

Transactions

AMERICAN FOUNDRYMEN'S ASSOCIATION

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TRANSACTIONS

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Progress Report on Investigation of Effect of High Temperatures on Steel Sands No. 3—Effect of Ramming

BY J. R. YOUNG*, ITHACA, N. Y.

INTRODUCTION

1. This report has been written to summarize the results of sand research carried on at Cornell University since publication of Progress Report No. 2¹. The work has been done under the direction of Subcommittee 6B7 on the Physical Properties of Steel Foundry Sands at Elevated Temperatures. Dr. H. Ries and the late Professor A. C. Davis personally guided the investigation.

2. The present program involves the making of tests under single-variable conditions in accordance with an outline suggested by the subcommittee.

3. The significance of the single-variable program might well be clarified at this point. It has been found extremely difficult, if not impossible, to correlate information derived from individual tests of many so-called "typical mixtures," for which no two sets of conditions are the same. While much useful data have been compiled, it still remains for the effect of each single variable to be investigated. The subcommittee, therefore, evolved a plan for the study of fundamentals of foundry sand behavior under which plan the simplest possible sand mixtures serve as a start for the work. It was thought that a good beginning could be made by holding sand grain size, type and percentage of bond, as well as moisture, constant, but varying the degree of ramming. This introduced only one variable and results have justified this procedure.

BASE SAND

4. A sand with over 90 per cent of the grain passing through the number 40 sieve and remaining on the number 50 sieve was prepared by screening a commercial grade of washed silica sand. A screen analysis of this base sand, given in Table 1, and Fig. 1, pictures the shape and uniformity of grain. Accuracy of grading

* American Foundrymen's Association Research Fellow, Cornell University.

¹ Young, J. R., "Progress Report on Investigation of Effect of High Temperatures on Steel Sands, No. 2—Comparison of Specimen Sizes," TRANSACTIONS, A.F.A., Vol. 49 (1941), pp. 646-686.

NOTE: This paper was presented before a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

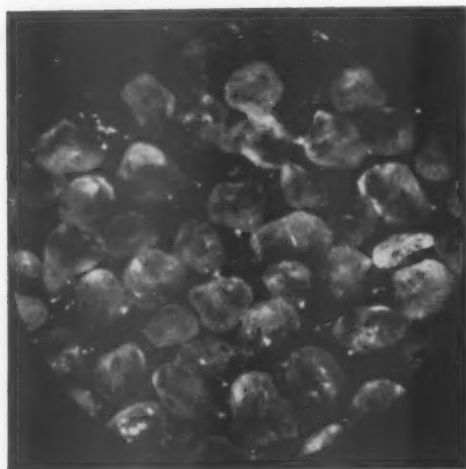


FIG. 1--BASE SILICA SAND USED FOR PREPARATION OF MIXTURES I AND II.

Table 1

SCREEN ANALYSIS OF BASE SILICA SAND

Per Cent Sand Retained

On 6 .....	..
12 .....	..
20 .....	..
30	trace
40	0.9
50	93.8
70	5.1
100	trace
140 .....	..
200 .....	..
270 .....	..
Pan .....	..
<hr/>	
	99.8

A. F. A. Fineness No. 40.4
 Grain Shape Sub-Angular

was promoted by mechanically splitting the whole useful portion of the screened sand to little more than that amount needed for analysis.

BASIC MIXTURES

5. The results which are recorded in this report were obtained from tests on two basic mixtures. Mixture I consists of 10 per cent fireclay and 90 per cent base silica sand. Mixture II was made up from 5 per cent fireclay and 95 per cent base silica sand. Mixtures I and II were each tested at two moisture contents. Different moistures are distinguished by the addition of capital letters to the mixture number (IA, IB, etc.). It is recognized that tests at only two moisture contents for each mixture cannot establish a trend. The same is true for all other variables. Further tests on the same mixtures are planned.

SPECIMEN PREPARATION

6. Mixtures were prepared in a laboratory mixer in 55 lb. batches, this amount being sufficient to provide specimens for a complete series of tests at one moisture content.

7. Sand and clay were thoroughly mixed dry by hand before being introduced into the muller. The mixtures were mulled for 3 min. before any addition of moisture. Neutral distilled water was added and the mixtures were mulled for another 5 min.

8. After mixing, the batches were put through a $\frac{1}{4}$ -in. riddle, split, and stored for 24 hours in large glass containers. The sands were riddled again ($\frac{1}{4}$ -in.) immediately before testing.

ROOM TEMPERATURE TESTS

9. Both 2 x 2- and 11/8 x 2-in. specimens were used for room temperature tests in order that additional data be made available

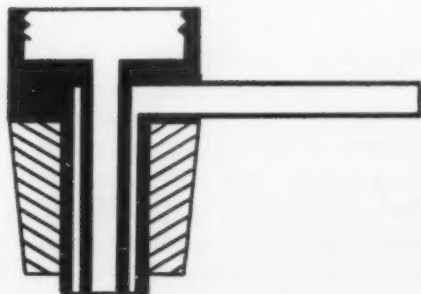


FIG. 2.—FITTING USED TO ADAPT STANDARD PERMEABILITY MACHINE TO TAKE $1\frac{1}{8}$ x 2-IN. SPECIMENS.

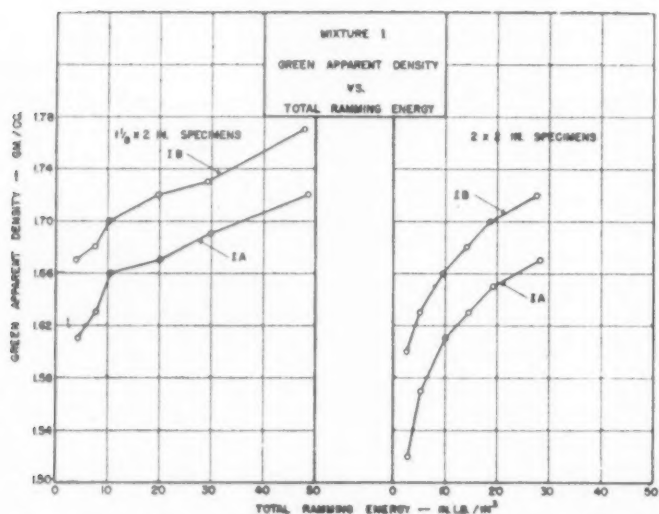


FIG. 3—GREEN APPARENT DENSITY VS. TOTAL RAMMING ENERGY, MIXTURE 1.

for comparison of specimen sizes.

10. For 2 x 2-in. specimens, moisture, green and dry compression, and permeability were all determined as recommended by A.F.A. standards. Compression tests on 1 1/8 x 2-in. specimens were made in a standard machine by using special compression heads². For making permeability tests on 1 1/8 x 2-in. specimens, a standard permeability apparatus was fitted with an adapter as shown in Fig. 2. Dry compression specimens were placed in a cold oven and brought to a temperature of 225°F. (107°C.) ($\pm 5^\circ\text{F.}$) (2.8°C.) at an approximate rate of 2.5°F. (0.14°C.) per minute. A temperature of 225°F. (107°C.) ($\pm 5^\circ\text{F.}$) (2.8°C.) was maintained for an additional 2 hours. Dried specimens were allowed to cool in a desiccator over calcium chloride before being tested. Green specimens were tested immediately on being prepared.

11. The degree of ramming was changed at will by varying the number and/or height of rammer-weight drops. A difference in ramming is evidenced by corresponding changes in green apparent density as well as in other physical properties; therefore, one can follow the effect of ramming by plotting compression, permeability, etc., against either green apparent density or total ramming energy. In this report both green apparent density and total ramming energy are used as bases for studying the effect of ramming.

² See p. 652 of reference 1.

12. Green apparent density is measured by dividing total specimen weight (grams) by final specimen volume (cubic centimeters).

13. Total ramming energy may be expressed as in the following equation:

$$E = \frac{(w \times d \times n) + (W \times D)}{v}$$

where

- E = total ramming energy (in. lb. per in.³)
- w = weight of cast-iron weight (lb.)
- W = total weight of moving parts (lb.)
- d = distance through which weight "w" falls (in.)
- D = amount of compaction of test piece (in.)
- n = number of times weight "w" is dropped
- v = final volume of specimen (in.³)

14. The factors w and W are fixed quantities but d and n can be varied as desired. D depends on d, n, and the nature of the sand mixture, and was measured to the nearest 1/50-in. The writer believes that total ramming energy is a more reliable index of degree of ramming than is green apparent density.

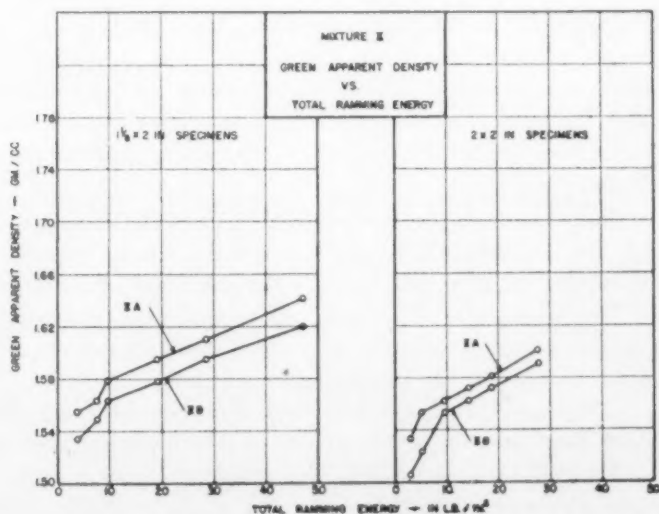


FIG. 4—GREEN APPARENT DENSITY VS. TOTAL RAMMING ENERGY, MIXTURE II.

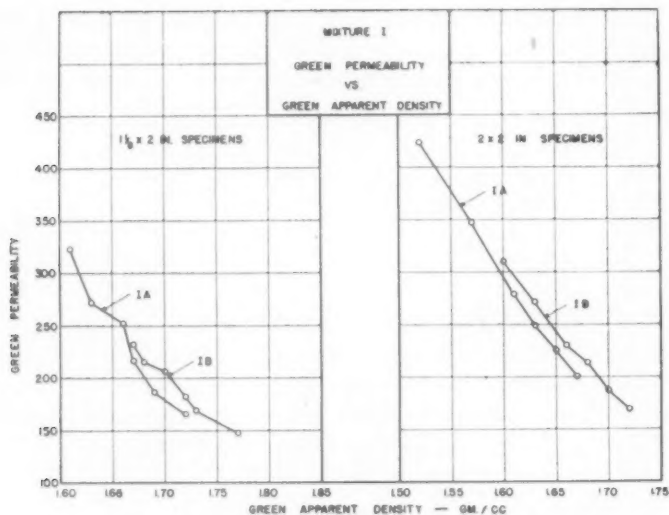


FIG. 5—GREEN PERMEABILITY VS. GREEN APPARENT DENSITY, MIXTURE I.

15. Values for green apparent density and total ramming energy for each ramming intensity are included in the results of room temperature tests (Tables 2 and 3).

HOT STRENGTH TESTS

16. Specimens for hot strength tests were dried in the same manner as dry compression specimens and were stored in drum desiccators over calcium chloride until needed. All hot strength tests were made in a dilatometer under shock-heating conditions. Only 1 1/8 x 2-in. specimens were tested because of limited furnace accommodations.

17. There has as yet been no standard method adopted by the A. F. A. for hot strength determinations. All figures reported in this paper resulted from tests made by the following procedure:

(1) The dilatometer is brought up to test temperature. This temperature is maintained for at least 15 min. before inserting a specimen to insure near equilibrium conditions.

(2) A cold specimen is sandwiched between upper and lower refractory discs and the whole placed on the lower furnace post.

(3) The specimen is soaked at test temperature for 15 min. An additional 5 min. is allowed for recovery of furnace temperature after insertion of the test-piece.

Table 2

RESULTS OF ROOM TEMPERATURE TESTS—1 1/8 x 2-IN. SPECIMENS

Mixture	Moisture, per cent	Ram	Green Apparent Density, gm. per c.c.	Total Ramming Energy, in. lb./in.3	Green Per- meability	Green Com- pression, lb./in.2	Dry Com- pression, lb./in.2
IA	3.85	1	1.610	4.4	323	3.79	23.1
		2	1.626	7.9	272	4.42	28.5
		3	1.657	10.6	252	4.79	27.3
		4	1.672	20.2	216	5.37	34.4
		5	1.687	29.8	186	5.69	37.4
		6	1.718	48.6	165	6.64	43.5
IB	5.05	1	1.665	4.0	232	2.16	32
		2	1.680	7.6	215	2.21	36.8
		3	1.695	10.3	206	2.21	40
		4	1.718	19.8	182	2.69	42
		5	1.733	29.3	168	2.84	47.5
		6	1.765	47.9	147	3.16	52
IIA	2.90	1	1.555	3.9	376	1.26	18.6
		2	1.563	7.5	358	1.50	22.7
		3	1.579	9.8	342	1.66	24.0
		4	1.595	19.1	313	1.75	27.1
		5	1.610	28.5	288	1.90	31.0
		6	1.641	47.1	265	2.05	33.7
IIB	1.85	1	1.534	3.9	416	1.66	8.2
		2	1.549	7.6	380	1.82	8.5
		3	1.563	9.9	371	1.97	9.1
		4	1.578	19.2	341	2.45	10.1
		5	1.595	28.5	314	2.57	10.8
		6	1.620	47.2	286	2.84	11.7

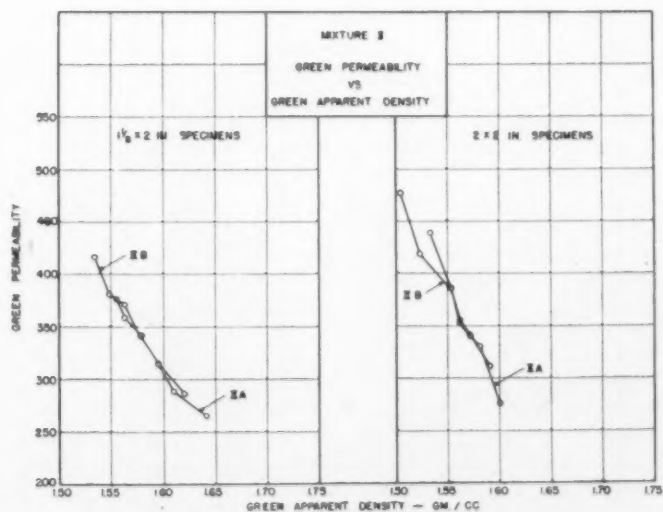


FIG. 6—GREEN PERMEABILITY VS. GREEN APPARENT DENSITY, MIXTURE II.

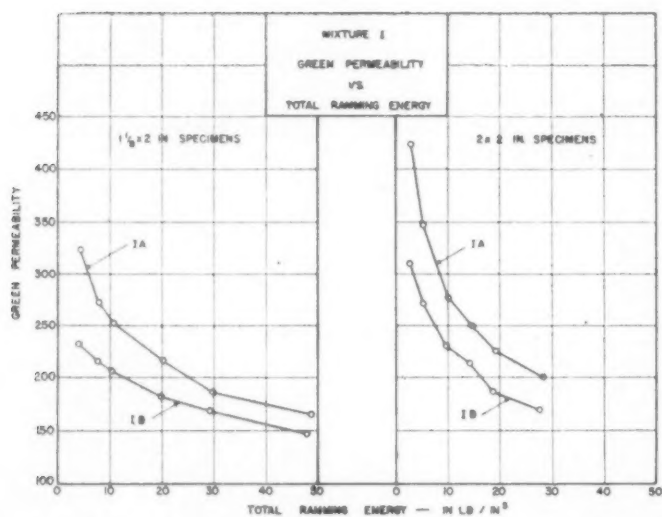


FIG. 7—GREEN PERMEABILITY VS. TOTAL RAMMING ENERGY, MIXTURE I.

(4) After a total period of 20 min. has elapsed, the specimen is compressed to failure between the upper and lower furnace posts.

18. Every hot strength figure appearing in Table 4 represents an average of at least 3 tests which agreed within ± 5 per cent. At

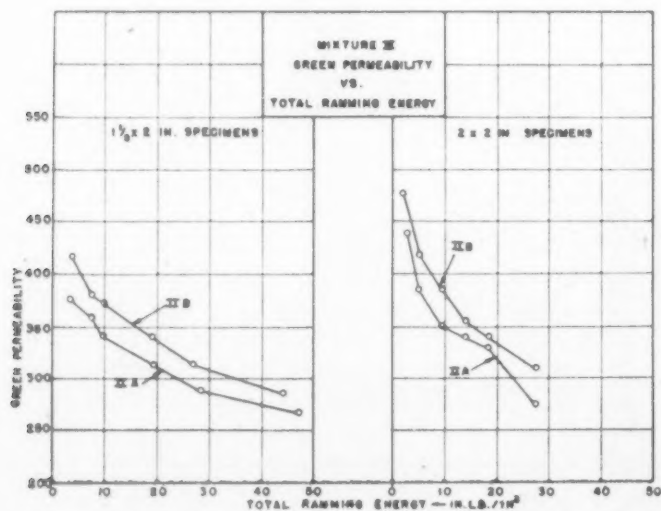


FIG. 8—GREEN PERMEABILITY VS. TOTAL RAMMING ENERGY, MIXTURE II.

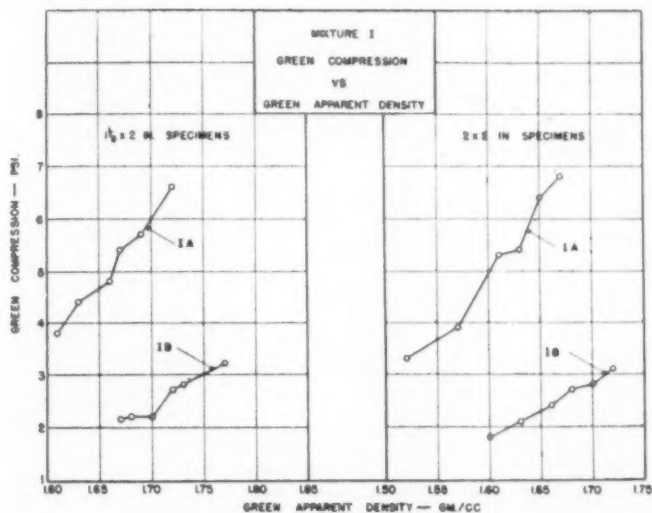


FIG. 9—GREEN COMPRESSION VS. GREEN APPARENT DENSITY, MIXTURE I.

times it was necessary to make as many as 6 or more tests before satisfactory agreement could be met. Possible reasons for erratic results are listed in the discussion following.

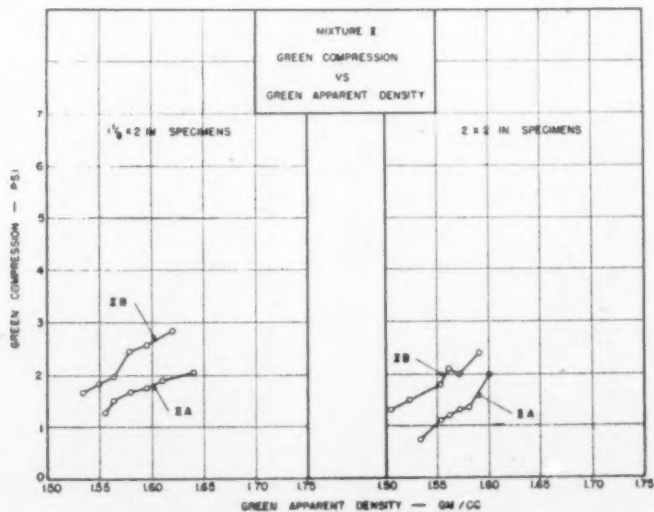


FIG. 10—GREEN COMPRESSION VS. GREEN APPARENT DENSITY, MIXTURE II.

Table 3

RESULTS OF ROOM TEMPERATURE TESTS—2 x 2-IN. SPECIMENS

Mixture	Moisture, per cent	Ram	Green Apparent Density, gm. per c.c.	Total Ramming Energy, in. lb./in. ³	Green Per- meability	Green Com- pression, lb./in. ²	Dry Com- pression, lb./in. ²
IA	3.85	1	1.523	2.9	423	3.25	18.2
		2	1.572	5.3	347	3.90	22.2
		3	1.610	10.0	278	5.27	29.0
		4	1.631	14.6	249	5.38	34.2
		5	1.650	19.2	225	6.40	36.2
		6	1.670	28.3	200	6.83	46.2
IB	5.05	1	1.601	2.6	310	1.80	34.5
		2	1.631	5.1	271	2.05	39.0
		3	1.660	9.6	230	2.35	43.5
		4	1.680	14.2	213	2.70	47.8
		5	1.699	18.7	187	2.82	50.0
		6	1.719	27.6	169	3.05	57.3
IIA	2.90	1	1.533	2.8	438	0.73	6.2
		2	1.553	5.0	386	1.10	7.5
		3	1.562	9.5	352	1.18	10.2
		4	1.572	14.1	340	1.30	15.3
		5	1.581	18.6	330	1.35	17.0
		6	1.601	27.5	276	2.00	20.0
IIB	1.85	1	1.505	2.8	477	1.3	3.9
		2	1.523	5.1	418	1.5	4.6
		3	1.553	9.6	385	1.8	5.9
		4	1.562	14.1	355	2.1	6.4
		5	1.572	18.6	341	2.0	6.8
		6	1.591	27.6	311	2.4	8.1

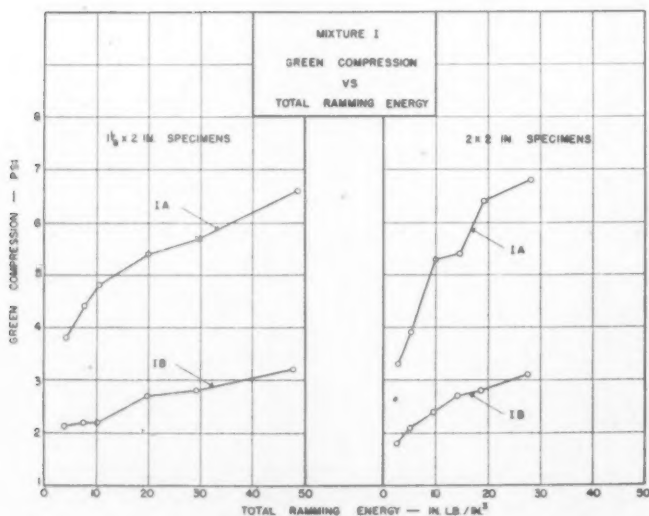


FIG. 11—GREEN COMPRESSION VS. TOTAL RAMMING ENERGY, MIXTURE I.

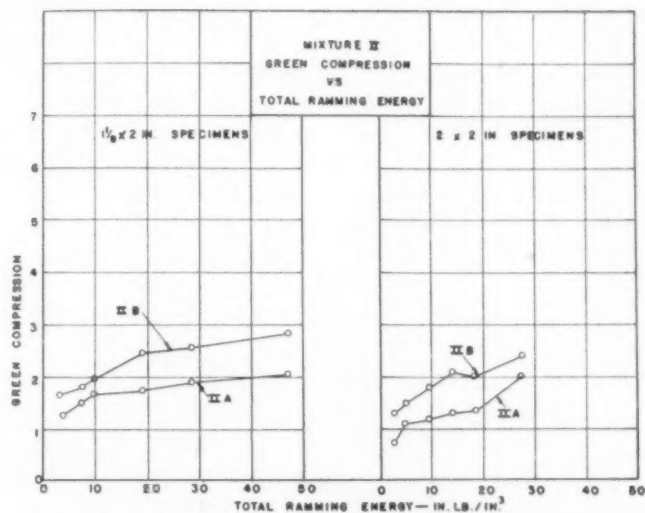


FIG. 12—Green Compression vs. Total Ramming Energy, Mixture II.

DISCUSSION

19. When completed, the first series of tests will include a study of the effect of degree of ramming on several mixtures of one particular kind of fireclay and silica sand of uniform grain size, each mixture to be tested at a number of different moisture contents

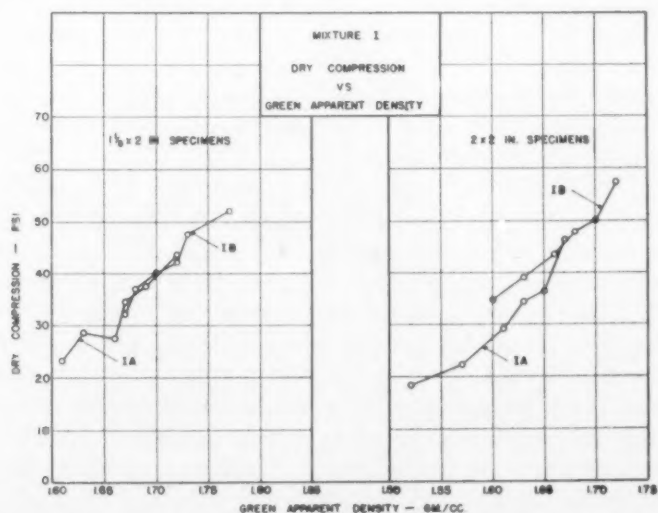


FIG. 13—Dry Compression vs. Green Apparent Density, Mixture I.

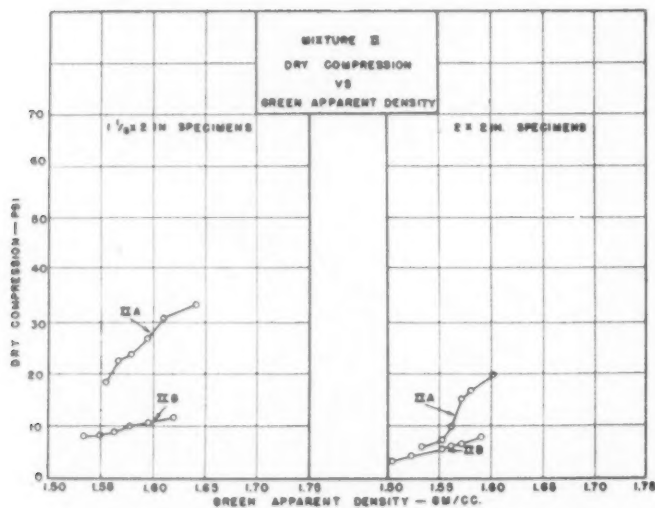


FIG. 14—DRY COMPRESSION VS. GREEN APPARENT DENSITY, MIXTURE II.

(the range of moistures to include the transition from very dry to very wet).

20. The extent of ramming intensities thus far used for this investigation approach useful maximum and minimum limits, as indicated by the curves of green apparent density versus total ramming energy (Figs. 3 and 4). Probably most ramming intensities met with in foundry practice are included between the extremes shown on the curves. It will be noted that for most of the curves presented in this report physical properties plotted against total ramming energy show a more uniform variation than when plotted against green apparent density.

21. The effect of ramming on permeability is represented in Figs. 5 through 8. As is to be expected, permeability decreases with increase in intensity of ram. The effect of ramming on permeability is more marked for 2 x 2- than 1 1/2 x 2-in. specimens.

22. The curves for green compression rise gradually with increase in intensity of ram, different mixtures being affected to different extents (Figs. 9 through 12). It is not evident from the curves, but if the spread of intensity of ramming were carried far enough, all curves would tend toward the horizontal at either end. The same would be true of the curves for permeability and dry compression. The curves for dry compression (Figs. 13 through 16) are similar to those for green compression.

23. Deformation data have not been included in the tables of results because it is felt that present available means of deformation measurement are not sufficiently refined for dependable results on quite plastic mixtures. An autographic compression-deformation apparatus may be necessary to the requirements of the current program of research. The writer wishes to point out, however, that the above does not imply condemnation of present equipment. Deformation measurement should be included as part of routine sand control testing.

24. Hot strength results are given in Table 4. The hot strength curves, shown in Figs. 17 through 20, are typical for silica sand-fireclay and other similar mixtures. The reasoning behind the choice of test temperatures should be fairly obvious from the appearance of the curves. The spacing of test temperatures in the neighborhood of 2000°F. (1093°C). is sufficiently close to show the location of peak hot strength.

25. As was indicated previously, some difficulty was experienced in checking hot strength test results. Several factors may have contributed to such irregularity:

(1) Sudden exposure to high temperatures might well have caused imperceptible cracks in test pieces. That the mixtures tested were affected by shock heating was proved by making several slow-heating tests³ and comparing with shock-heating tests. Hot strengths after slow heating were considerably greater than after shock heating.

Table 4

RESULTS OF HOT STRENGTH TESTS—1½ x 2-IN. SPECIMENS

Temperature		800	1200	1600	1800	1900	2000	2100	2200	2400
(*F.)		427	649	871	982	1038	1093	1149	1204	1310
(*C.)										
Mixture	Ram									
IA	1	33	59	65	89	109	177	161	87	19
	2	41	50	60	93	132	196	169	89	20
	4	48	57	68	112	156	240	179	123	21
	5	69	83	102	150	247	346	250	149	21
	6	79	96	130	200	316	401	289	156	23
IB	1	66	90	121	210	220	353	347	144	30
	6	113	157	251	377	433	560	428	282	52
IIA	1	16	22	21	40	47	56	92	51	19
	6	41	50	61	75	96	127	161	136	36
IIB	1	12	8.5	10	11	16	23	28	20	10
	6	18	18	21	24	27	53	70	55	20

³ "Slow heating," in this report, means the heating of specimens from room to test temperature at a rate not exceeding 5°F. per minute.

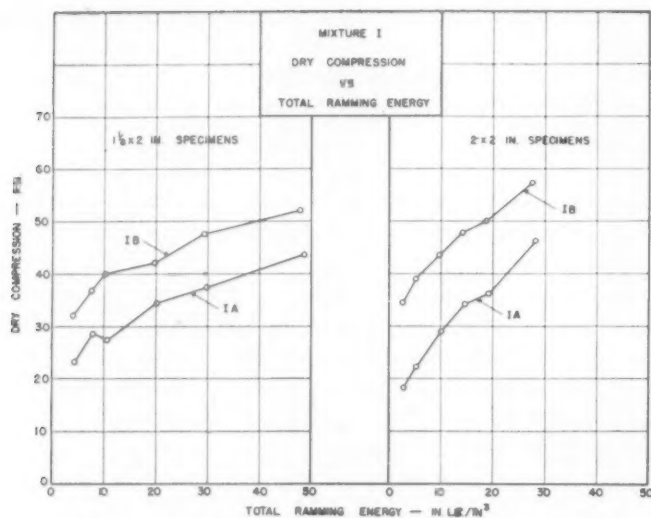


FIG. 15—DRY COMPRESSION VS. TOTAL RAMMING ENERGY, MIXTURE I.

- (2) The effect of slight but unavoidable variations in ramming of specimens is, undoubtedly, magnified in high temperature testing.
- (3) Outside sources of vibration, though not an obvious factor,

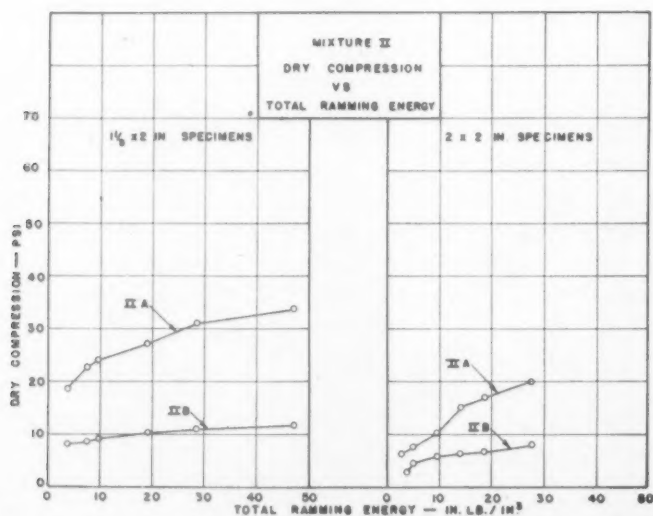


FIG. 16—DRY COMPRESSION VS. TOTAL RAMMING ENERGY, MIXTURE II.

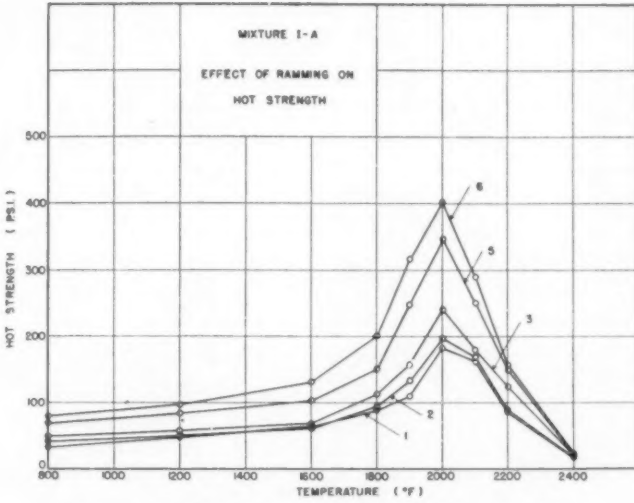


FIG. 17—EFFECT OF RAMMING ON HOT STRENGTH, MIXTURE IA.

may considerably influence individual results of tests on weak mixtures. This problem was encountered at Cornell and was met by partially spring-supporting the furnace.

(4) Because the slope of the curves in the vicinity of peak hot strength is so high, relatively slight variations in temperatures are

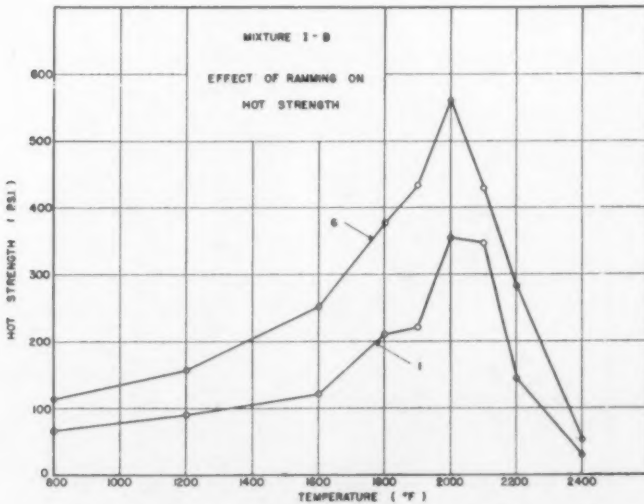


FIG. 18—EFFECT OF RAMMING ON HOT STRENGTH, MIXTURE IB.

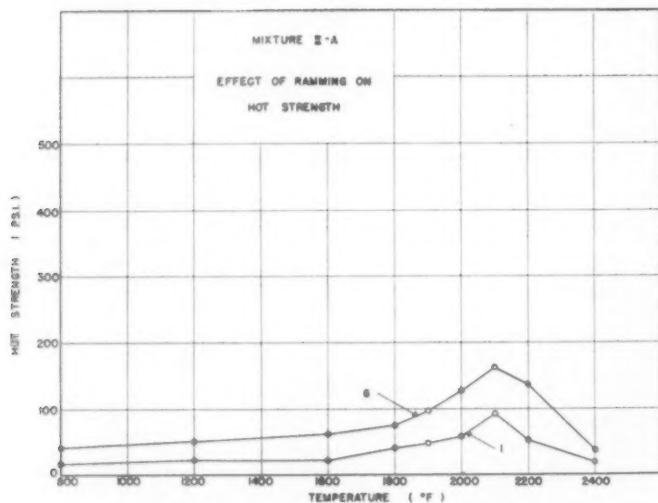


FIG. 19—EFFECT OF RAMMING ON HOT STRENGTH, MIXTURE IIA.

accompanied by disproportionate changes in hot strengths. Unless very close furnace temperature control is exercised, considerable error may occur in this range.

26. Figure 17 includes hot strength curves for mixture 1A at 5 different intensities of ramming. Hot strength tests of sub-

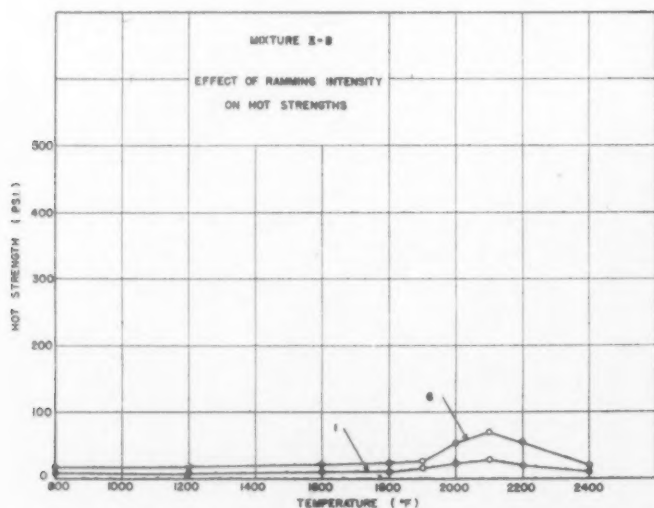


FIG. 20—EFFECT OF RAMMING ON HOT STRENGTH, MIXTURE IIB.

quent mixtures were made for only the hardest and lightest rams of each because of the regularity shown by these curves.

27. It is apparent from all curves (Figs. 17 through 20) that for the mixtures tested, hot strength increases gradually with temperature, rising sharply to a maximum between 2000 and 2100°F. (1093 and 1149°C.) and then falling off rapidly to a low value at 2400°F. (1316°C.). Beyond 2400°F., hot strength continues to decrease with increase in plasticity of the specimen.

28. Figures 17 and 18 indicate that with increase in ramming, the peak hot strength tends to shift to a lower temperature, and a comparison of these curves with Figs. 19 and 20 makes it obvious that the peak of hot strength depends too on the percentage of clay in the mixture. Mixture I (10 per cent fireclay) shows its maximum hot strength near 2000°F. (1093°C.). Mixture II (5 per cent fireclay) shows a maximum hot strength closer to 2100°F. (1149°C.).

SUMMARY

29. Although results presented thus far on the effect of single variables are limited to those acquired by an incomplete investigation on only two very simple sand mixtures, it may be well to list conclusions which might be drawn from these tests:

(1) Total ramming energy appears to be a more reliable index of degree of ramming than is green apparent density.

(2) With increase in total ramming energy (and green apparent density) both green and dry compression increase and permeability decreases.

(3) The same general trends can be indicated by use of either $1\frac{1}{8} \times 2$ - or 2×2 -in. specimens, but the effect of ramming on both specimen sizes is not the same¹.

(4) For the mixtures tested, increase in ramming intensity seems to lower the temperature of peak hot strength.

(5) For the mixtures tested, the temperature of peak hot strength is apparently dependent to some extent on the percentage of bond in the sand. Maximum hot strength is reached at higher temperatures for mixtures of lower percentage of bond.

(6) Hot strength varies with moisture and per cent bond in much the same manner as dry compression varies with moisture and per cent bond.

DISCUSSION

Presiding: N. J. DUNBECK, Eastern Clay Products Co., Eifort, Ohio.

Co-Chairman: C. M. SAEGER, JR., National Bureau of Standards, Washington, D. C.

CHAIRMAN DUNBECK: As the intensity of ramming increased, did the green strength and dry strength increase at about the same rate, or did one of them increase at a more rapid rate than the other?

MR. YOUNG: They increased at approximately the same rate. I would want to run further tests at different moisture contents before I would draw any conclusions as to the comparison between rates at which green and dry strengths increase.

CHAIRMAN DUNBECK: Was the hot strength appreciably lower with less intensive ramming?

MR. YOUNG: Yes. It was lower by 100 per cent or more.

MEMBER: Was the standard A.F.A. testing sand used in these experiments?

MR. YOUNG: No, it was a sand sifted from a commercial grade of washed silica sand.

MEMBER: Was there a mulling interval?

MR. YOUNG: Yes. We used a mulling time of 3 min. dry and 5 min. wet.

E. PRAGOFF, JR.¹: Were the tests for hot strength made on green or on dry specimens?

MR. YOUNG: On dry specimens.

MR. PRAGOFF: Were the specimens kept in a desiccator prior to the time of testing?

MR. YOUNG: Yes.

MR. PRAGOFF: I am interested in the ramming because I think it helps the foundryman apply this sort of work more directly to his everyday jobs. We know that the molder frequently will accommodate the sand to the job, taking care of the variations in size of castings that he may have to make. I am sure that work of this sort ought to be encouraged to help the foundryman apply it more successfully.

HENRY W. MEYER²: What length of time were the specimens heated or soaked before the hot strength was determined?

MR. YOUNG: The specimens were soaked for a period of 20 min.

¹ Hercules Powder Co., Wilmington, Del.

² General Steel Castings Corp., Commonwealth Div., Granite City, Ill.

Welding of Medium Carbon Steel Castings by the Metal Arc Process

BY S. E. MUELLER*, MILWAUKEE, WIS., A. B. SMITH**,
CHICAGO, ILL., AND J. F. OESTERLE†, MADISON, WIS.

Abstract

The object of this research is to study the metallurgical effects of preheat, welding procedure and subsequent heat treatment on welds in a plain medium carbon steel and a typical air hardening, low alloy, steel casting. By analyzing the results of this investigation it is hoped that a definite welding method might be recommended so as to produce a welded structure, comparable to the parent metal and free of detrimental welding defects. The authors have attempted to show that preheating is essential in the satisfactory welding of medium-manganese-molybdenum steel castings (0.35 to 0.40 per cent carbon, 1.25 to 1.50 per cent manganese, 0.20 per cent molybdenum); and that stress relieving must follow the welding operation. They also indicate that shrinkage stresses are high where a martensitic structure obtains on cooling. A comparison is made with a plain carbon steel showing that welding stresses have no detrimental effect. The authors have not lost sight of the fact, that to be of optimum value, the methods suggested must be practical from the foundryman's viewpoint.

INTRODUCTION

1. Fusion welding has been employed for repairing minor defects in steel castings for many years. The metal arc process is most generally used today and little difficulty has been encountered in low carbon steels. High carbon steels and low alloy steels, however, that have air hardening characteristics, present problems

* Foundry Research Engineer, The Falk Corporation.

** Marine Surveyor, American Bureau of Shipping.

† Associate Professor of Metallurgy, University of Wisconsin.

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to the foundryman. It is with the idea of contributing to the solution of the problem as a whole that the present paper was initiated.

2. Welding by the metal arc process consists essentially of a localized progressive melting of the base metal and a metal electrode. The temperature gradient accompanying welding naturally imposes a stress gradient in both the base metal and the weld metal. The temperatures that obtain in welding introduce further considerations of stress because only limited control of these gradients is possible and steel must naturally conform to fundamental metallurgical reactions when these reactions lie within the heating and cooling cycle.

3. For each pass made in the operation of welding, the base metal or the metal from the preceding pass is heated to the welding temperature and then allowed to cool by radiation and conduction. After several passes have been made, it is quite natural to assume that the last pass may act as a normalizing operation to the previous passes excepting only the pass immediately preceding. Plain carbon steels, reacting quite rapidly to normalizing treatments, are more or less improved by this heat treating cycle. Low alloy steels, more or less sluggish in their reactions to heat treatment, are very easily hardened in a normalizing treatment. Rates of heating and cooling are decidedly important. Modifications may be obtained when the base metal is pre-heated as a preliminary to a welding operation. Stress relief, that is, post-heating of the weld to a temperature of about 1200°F., releases shrinkage stresses and draws or tempers the hardened zone. This tempering causes the transformation of any residual austenite to ferrite and cementite, the decomposition of martensite into ferrite and cementite and the growth and spheroidization of the carbide particles.

4. Factors that influence the rate of heat input in the metal arc process are the function of the arc power in watts, and the speed of travel of the electrode. The arc voltage is not a factor variable at will, so, for a constant welding speed we can express the rate of heat input simply by the current. The current used varies with the size and type of electrode and welding conditions. The welding method used is commonly known as the "shielded arc" process.

5. Factors that influence the rate of heat dissipation as they are influenced by the base metal are: temperature, mass, heat conductivity and heat capacity; and as they relate to the weld metal,

heat dissipation is affected by radiation and convection from a slag covered surface.

6. Cooling rates that obtain after the metal has been heated to the liquid state by welding are determined by the factors mentioned in the two previous paragraphs.¹ An additional thought in this connection would involve a consideration of the latest information on isothermal transformation and also on cooling-rate transformation. The literature on this is increasing day by day, and much information can be obtained from articles such as those originating from the research laboratory of the United States Steel Corporation^{2, 3}. High temperature properties of both base metal and weld metal must not be neglected. The stresses and strains set up by temperature gradients and by critical transformation gradients are naturally imposed at elevated temperatures. The ability or inability of metal to deform under stress determines the effectiveness of the weld.

7. It can be readily seen that due to the large variety of compositions of cast steels no definite specifications can be set up for electrodes that will produce weld metal having properties comparable to the base metal. However, the American Society for Testing Materials has set up tentative specifications for welding electrodes. "These specifications cover lightly coated and covered metal arc-welding electrodes for the welding of carbon and low alloy steels of weldable quality. The electrodes are classified on the basis of usability and the ultimate strength and elongation in two inches of all-weld-metal specimens in the stress relieved condition."⁴ Commercial electrodes from reputable manufacturers produce high quality weld metal. A ductile deposit having a low yield strength is desirable if cracking in the heat-affected zone of the base metal is to be kept at a minimum. Because of the method by which weld metal is deposited, a columnar grain structure obtains immediately after the pass. Figure 1 shows diagrammatically how the cooling of the first bead is arrested by deposition of the succeeding one and describes the possible structures attendant thereto. With the proper sequence of passes the heat-affected zone will be "heat treated" so as to eliminate the hard structure.

¹ Henry, O. H., and Clausen, G. E., "WELDING METALLURGY" (New York: American Welding Society, 1940), p. 199.

² Grange, R. A., and Kiefer, J. M., "Transformation of Austenite on Continuous Cooling and Its Relation to Transformation at Constant Temperature", *TRANSACTIONS, American Society for Metals*, vol. 29, No. 1 (1941), pp. 85-114.

³ Aborn, Robert H., "Metallurgical Changes at Welded Joints and the Weldability of Steels", *WELDING RESEARCH COMMITTEE*, vol. 5, no. 10 (1940), pp. 417-421.

⁴ A.S.T.M. Tentative Specifications for Iron and Steel Arc-Welding Electrodes, A283-40T.

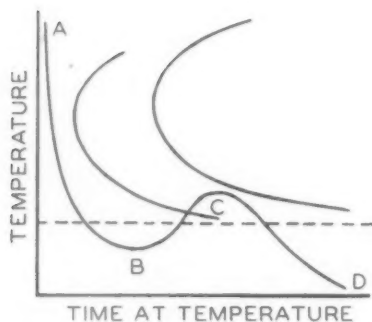


Fig. 1.—Curve ABCD is the Time-Temperature Record of the Zone Close to a Weld in Thick Plate.

From A to B the zone is cooling rapidly enough to pass the nose of the transformation curve. As it passes below the martensite temperature, some of the austenite transforms to martensite, the transformation continuing until the temperature falls to B. At B the zone is feeling the effects of the next bead. The fall in temperature is arrested; likewise the further decomposition of austenite to martensite is stopped. Upon crossing the left transformation curve, the remaining austenite commences to transform to bainite. Meanwhile the martensite is changing to a mixture of ferrite and cementite; that is, the temperature has risen sufficiently high for the martensite to be tempered. Beyond C the second bead has passed by and the zone cools to room temperature along curve CD. (From WELDING METALLURGY—O. H. Henry and G. E. Claussen.)

PROCEDURE

8. The general procedure was to weld two types of medium carbon steel castings under various welding conditions, the first being a steel having properties as given in Table 1. The plain carbon steel is typical of general medium carbon steel castings and has a carbon content (0.33 per cent) about that which is generally conceded to be the limit for welding without preheating. In contrast, manganese molybdenum steel was selected as being representative of the low alloy air hardening type.

PROCEDURE FOR THE PLAIN CARBON STEEL

9. Three cast blocks 6-in. x 6-in. x 14-in. were prepared for welding by chipping four transverse "U" grooves, $\frac{3}{4}$ -in. wide by $\frac{3}{4}$ -in. deep across each. The casting size was selected so as to have a large mass of parent metal for rapid heat dissipation comparable to that obtained in a large casting; and, to give sufficient rigidity to minimize distortion, thus obtaining the maximum shrinkage stresses due to welding. The first block was in the "as cast" condition, the second, fully annealed and the third preheated to 300°F. when welded. These castings have been designated as A, B, and

Table 1

MATERIALS

CASTINGS

Material	Blocks Designated	Type Steel	Chemical Analysis, per cent					Mechanical Properties (Average)		
			C	Si	Mn	P	S	Tensile Strength, psi.	Yield Point, psi.	Elongation, per cent in 2-in.
Plain Carbon Steel Mn-Mo Steel	A-B-C-1-2-3-4-5	Electric Acid Open Hearth	0.38	0.35	1.50	0.033	0.030	76,000	46,000	27
			0.38	0.35	1.50	0.033	0.030	90,000	58,000	25

WELDING ELECTRODES

Electrode Designation	A.S.T.M. Classification Number ¹	Coating Type	Mechanical Properties of Deposited Weld Metal ² (Average)			Mechanical Properties of Welded Metal ² (Average)			Elongation, per cent in 2-in.
			Tensile Strength, psi.	As Welded Yield Point, psi.	Elongation, per cent in 2-in.	Tensile Strength, psi.	Yield Point, psi.	Elongation, per cent in 2-in.	
A	E-6030	Heavy Mineral	68,000	54,500	29	66,000	52,000	37	37
B	E-6010	Heavy Cellulosic	67,000	56,000	28	64,000	53,500	34	34
N	E-6012, E-7011	Heavy Mineral	75,000	57,000	24	71,000	54,000	28	28
M	E-7010	Heavy Cellulosic	87,000	65,500	20	79,000	57,000	31	31
73	D-7020	Heavy Mineral	76,000	62,500	26	72,000	60,000	33	33
100	None	Heavy Mineral	103,000	92,000	18	108,000	95,000	19	19

¹ Tentative Specifications for Iron and Steel Arc-Welding Electrodes Serial Designation: A 233-40T.² Average mechanical properties as obtained from the electrode manufacturers.

Table 2
WELDING PROCEDURE FOR THE MEDIUM CARBON STEEL CASTINGS

Block Number	Weld Specimen Number	Castings Condition	Preheat	Subsequent Heat Treatment	Welding Number	Electrode Size	Number of Passes	Amps	Welding Current Volts	Polarity
A	A-A	Green	None	None	A	3/16	15	170-190	26-28	Reverse
	A-B				B	3/16	16	160-180	26-28	Reverse
	A-N				N	3/16	14	170-190	26-28	Straight
	A-M				M	3/16	15	170-190	26-28	Reverse
B	B-A	Annealed	None	None	A	3/16	16	170-190	26-28	Reverse
	B-B				B	3/16	15	160-180	26-28	Reverse
	B-N				N	3/16	14	170-190	26-28	Straight
	B-M				M	3/16	16	170-190	26-28	Reverse
C	C-A	Annealed	300°F.	None	A	3/16	14	170-190	26-28	Reverse
	C-B				B	3/16	16	160-180	26-28	Reverse
	C-N				N	3/16	15	170-190	26-28	Straight
	C-M				M	3/16	14	170-190	26-28	Reverse

C, respectively. The casting conditions were selected since they correspond to the most general states at which castings are welded. Furthermore, the welding of the "green" block will determine whether normal segregation of the "as cast" condition is detrimental.

10. The four corresponding grooves in each block were welded with the same electrode, the types being *A*, *B*, *N* and *M* as noted in Table 1. The electrodes selected are in the A.S.T.M. classes generally used for the welding of plain medium carbon steel castings. The welding procedure used is shown in Table 2 and conforms generally with good practice and the recommendations of the electrode manufacturer. No peening of the welds was permitted.

11. The welder was instructed to take no special precautions in the preparation of the test pieces, but rather to use the same technique as would be employed in ordinary shop work. As a result of these instructions we believe that more usable results have been obtained, than if a special technique, which might not be rigidly adhered to under production conditions, has been used.

12. The following metallurgical analyses of the welds were made:

(1) The blocks were radiographed in order to ascertain whether cracking had occurred due to welding.

(2) Drillings were taken of the deposited weld metal and chemically analyzed.

(3) Specimens were cut transversely from each weld which were used for hardness surveys and microscopic examinations.

(4) A portion of each block was annealed and the changes in hardness and micrographic structure noted.

PROCEDURE FOR THE MANGANESE-MOLYBDENUM STEEL

13. The procedure followed for the low alloy steel castings was generally the same as for the plain carbon steel with certain essential differences. All blocks were taken from a fully annealed casting as it is necessary to normalize or anneal this type steel prior to any chipping or machining operations.

14. Five blocks 6-in. x 6-in. x 14-in. were prepared for welding in the same manner as for the plain carbon steel and were welded at various pre-heat temperatures and subjected to subsequent stress relief as noted in Table 3.

Table 3
WELDING PROCEDURE FOR THE MANGANESE-MOLYBDENUM STEEL CASTINGS

Block Number	Weld Specimen Number	Casting Condition	Preheat	Subsequent Heat Treatment	Welding Electrode Number	Welding Electrode Size	Number of Passes	Welding Current		
								Volts	Amperes	Polarity
1	11	Annealed	None	None	73	3/16	3	28-30	185-215	Straight
	12							30-32	160-180	
	13							32-34	285-315	
	14							30-32	225-260	
2	21	Annealed	300° F.	None	100	3/16	6	30-32	175-190	Straight
	22							32-34	275-310	
	23							30-32	245-265	
	24							30-32	180-200	
								30-32	160-180	
								32-34	280-300	
								32-34	260-280	
								30-32	190-210	
3	31	Annealed	600° F.	None	100	3/16	8	30-32	160-180	Straight
	32							32-34	290-310	
	33							30-32	250-270	
	34							30-32	160-180	
								30-32	280-300	
								32-34	260-280	
								30-32	170-190	
								30-32	140-160	
4	41	Annealed	300° F.	Stress Relieve 1200° F. 1½ Hr. Per Inch	73	3/16	4	30-32	224-240	Straight
	42							32-34	150-170	
	43							30-32	230-260	
	44							30-32	220-240	
	51							30-32	160-180	
	52							32-34	240-260	
	53							30-32	220-240	
	54							30-32	150-170	
5	51	Annealed	600° F.	Stress Relieve 1200° F. 1½ Hr. Per Inch	100	3/16	7	30-32	240-260	Straight
	52							32-34	220-240	
	53							30-32	160-180	
	54							32-34	240-260	

Table 4

WELDING PROCEDURE FOR THE SINGLE PASS WELDS ON THE
MANGANESE-MOLYBDENUM STEEL CASTINGS

Welding Condition	Welding Number	Electrode Size, Inches	Welding Current		
			Amperes	Volts	Polarity
Room Temperature No Preheat	72	3/16	185-210	30-32	Straight
300°F. Preheat	73	3/16	180-200	30-32	Straight
600°F. Preheat	73	3/16	160-180	32-34	Straight

15. In order to study the effect of preheat, block 1 was welded at room temperature, block 2 at 300°F. preheat and block 3 at 600°F. preheat. Preheating was accomplished by heating the castings in an oven to the temperature desired which was maintained by means of a gas torch on the bottom of the block while the top was covered by asbestos sheet with the exception of the groove being welded. Temperatures were checked by means of a thermocouple.

16. The top preheat temperature of 600°F. was selected as it is about the maximum which can be resorted to in the foundry without special facilities.

17. For the purpose of determining whether stresses which occur in cooling from the preheat to room temperature are detrimental, blocks 4 and 5 were welded at 300°F. and 600°F. respectively, which was immediately followed by a stress relief anneal at 1200°F. for one hour per inch of thickness.

18. Two types welding electrodes were used, one groove being welded with 3/16-in. rod and one with 1/4-in. rod of each type. By using two sizes of electrodes a variation in the rate of heat input was obtained for investigation. The welding procedure used is given in Table 3, the passes being put on in succession without waiting for the previous bead to cool to the preheat temperature. The casting temperature in general was read after each pass and if the rise exceeded 50°F. it was allowed to cool before proceeding.

19. The same metallurgical observations were made as listed in the procedure for the plain carbon steel.

20. Subsequently, portions of blocks 4 and 5 were given the

Table 5
CHEMICAL ANALYSIS OF DEPOSITED WELD METAL

Electrode Designation				Per cent		Cr.	Ni.	Mo.	V.
	C.	Si.	Mn.	P.	S.				
A	0.10	0.061	0.42	0.016	0.023	—	—	—	—
B	0.11	0.079	0.57	0.011	0.024	—	—	—	—
N	0.10	0.074	0.39	0.019	0.023	—	—	—	—
M	0.12	0.210	0.33	0.011	0.023	—	—	0.47	—

following heat treatments. (1) Annealed at 1550°F. (2) Normalized from 1550°F. (3) Quenched from 1550°F. in water at 130°F. (4) As 3, drawn at 1150°F. Hardness surveys of specimens from each were made. These treatments follow shop practice for various types of the manganese-molybdenum steel castings depending on the purpose for which they are intended.

21. During the progress of the investigation, it was found necessary, in order to more fully analyze the metallurgical changes due to welding, to make single bead welds on castings under the same conditions as for the multiple pass welds. Table 4 shows the procedure used. From each weld, specimens for hardness surveys and microscopic examination were prepared.

EXPERIMENTAL RESULTS PLAIN CARBON STEEL

22. The plain carbon steel, as may be noted from Table 1, conforms in chemical composition to the medium carbon steel casting classification of the A.S.T.M.⁵

23. The specifications pertaining to welding of this grade limit the carbon content to a maximum of 0.35 per cent with 0.60 per cent manganese in castings for welding but require subsequent heat treatment. It may be noted that the carbon and manganese are tied together and for each 0.01 per cent reduction in carbon an increase of 0.04 per cent manganese is permitted up to 1.00 per cent. They also provide that the castings are to be normalized or annealed before welding so as to refine the cast structure and relieve shrinkage stresses due to cooling.⁶

24. The castings used in this investigation were purposely selected as representing the top limit as to carbon and manganese content considered suitable for welding without preheat.

⁵ *Metals Handbook*, AMERICAN SOCIETY FOR METALS, (1939), p. 959

⁶ A.S.T.M. specifications for Carbon Steel Castings Suitable for Welding, A216-39T, A216-39T, A217-39T.

25. The electrodes chosen for the welding of the plain carbon steel castings were selected because they are typical of the commercial types that may be used for the welding of this class of steel. Rods "A", "B" and "N" are straight carbon electrodes, and "M" is of the plain molybdenum type. All of these conform to tentative specifications set up by A.S.T.M.

26. Drillings were taken of the deposited weld metal for chemical analysis, the results of which are shown in Table 5.

27. A review of the literature reveals that the effect of phosphorus on the quality of welds is relatively slight in amounts up to 0.15 per cent.⁷ Sulphur up to 0.05 per cent is not considered detrimental unless there are high content segregations which may cause porosity or small cracks in the adjacent weld metal⁸. This "hot shortness" will be avoided if the manganese content is high so harmless manganese sulphides will form rather than the low melting point iron sulphides.

28. The effects of the so-called impurities in steels may be eliminated in any further discussion since the amounts present in the castings under investigation are below that considered to be detrimental.

29. In the welding of steel castings cracks may originate due to improper technique being employed. "These cracks sometimes spread as the welding progresses, two or three layers beneath the deposited surface. The cracks may extend from 40 per cent to 90 per cent through the weld and still be detectable only by x-ray or similar examination⁹."

30. It is easy to conceive how a transverse specimen could be cut from a weld for microscopic examination and not show evidence of cracking whereas at some other location the welding conditions were such as to produce cracks. For this reason, all welds were subjected to radiographic examination.

31. The plain carbon steel castings showed no evidence of cracking or detrimental defects in the welds either in the x-ray photographs or under microscopic examination, as shall be seen later.

⁷ Claussen, G. E., and Spraragen, W., "The Effect of Phosphorus on the Welding of Steel," WELDING RESEARCH COMMITTEE, vol. 18, no. 4 (1939), pp. 123-130.

⁸ Claussen, G. E., and Spraragen, W., "The Effect of Sulphur on the Welding of Steel," WELDING RESEARCH COMMITTEE, vol. 18, no. 2 (1939), pp. 44-49.

⁹ Ash, E. J., and Underwood, C. M., "X-Ray and Welding the Foundryman's Aid to Quality Steel Castings," TRANSACTIONS, American Foundrymen's Association, vol. 43, (1935), p. 493.

Table 6
HARDNESS SURVEYS OF PLAIN CARBON STEEL CASTINGS

Block Designation and Condition for Welding	Welding Electrode	Hardness—Rockwell "B"				
		Parent Metal Range	As Welded Weld Metal Range	Heat Affected Zone Max. Metal Range	Annealed Subsequent to Welding Weld Metal Heat Affected Zone Max.	
A Welded in Green Condition	A	82-84	73-74	90	64-67	79
	B		77-79	92	64-66	80
	N		86-87	91	69-71	79
	M		89-92	96	72-73	79
B Annealed Welded at Room Temperature	A	77-79	75-78	91	62-65	77
	B		75-77	94	64-66	79
	N		79-82	96	66-72	79
	M		85-87	92	73-75	79
C Annealed Welded at 300°F. Preheat	A	77-79	76-78	92	64-66	80
	B		75-78	93	65-66	79
	N		85-88	94	70-71	79
	M		86-92	95	71-74	79

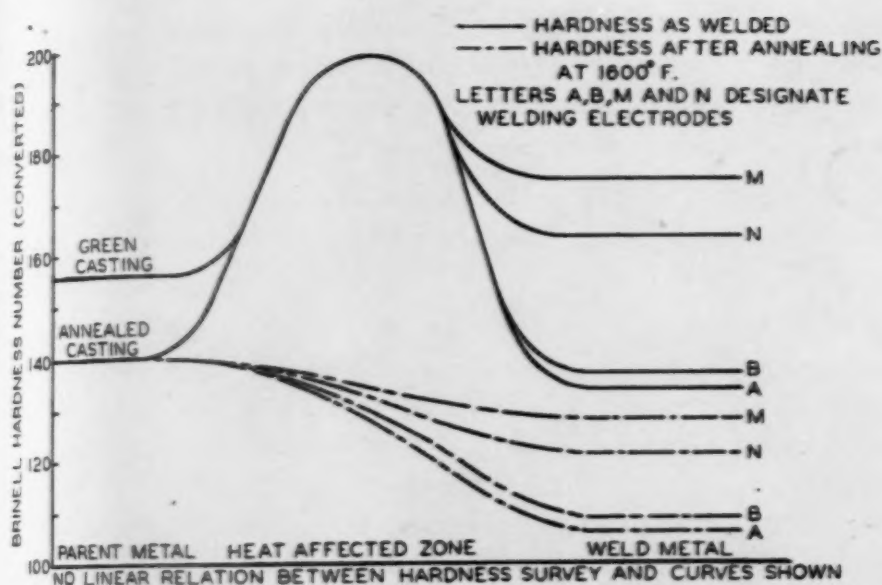


Fig. 2—Comparative Hardness Curves of Welds in the Plain Carbon Steel Castings.

Hardness Surveys

32. Hardness surveys of a weld give a good indication of the structure to be expected and comparative mechanical properties.

33. Table 6 is a summary of the surveys of the welds made in the plain carbon steel castings under the three conditions noted. These have been combined to form the curves shown in Fig. 2; hardness readings having been converted from Rockwell "B" to the Brinell hardness numbers. No uniform distance between readings was used in making the surveys so no linear relation between the curves and hardness in the weld heat-affected zone is shown. The authors found that if readings were taken at regular equal intervals across the heat-affected zone it was frequently the case that the maximum hardness was missed as the interval, of necessity due to size of impression, was too large. For this reason, readings were taken all around the weld so as to determine the maximum hardness which is the important consideration.

34. It will be noted that the average maximum hardness for the the four welds in each block was the same whereas one would expect that the 300°F. preheat in block "C" would lower its maximum reading. This is accounted for since the welds are multiple pass where the softening effect of each subsequent bead is greater than the effect of preheat.

35. It appears desirable to have castings of this analysis receive

either a stress relieving or annealing treatment, subsequent to welding, so the loss in ductility of parent metal in the heat-affected zone and the welding shrinkage stresses, will not cause cracking when under load in service.

36. The effect of a full anneal is shown on the curves, the hardened zone having disappeared and the hardness of weld metal lowered considerably.

37. Referring to the curves and Table 1 and comparing the average mechanical properties of the parent metal with the stress relieved weld metal, it is observed that while weld metal "M" has a hardness somewhat less than that of the casting its mechanical properties are superior. With electrodes, *A*, *B* and *N*, while the tensile strength is lower than that of the casting, the yield point and elongation in all cases is superior. These being the significant properties it may be said that any of the electrodes can pro-

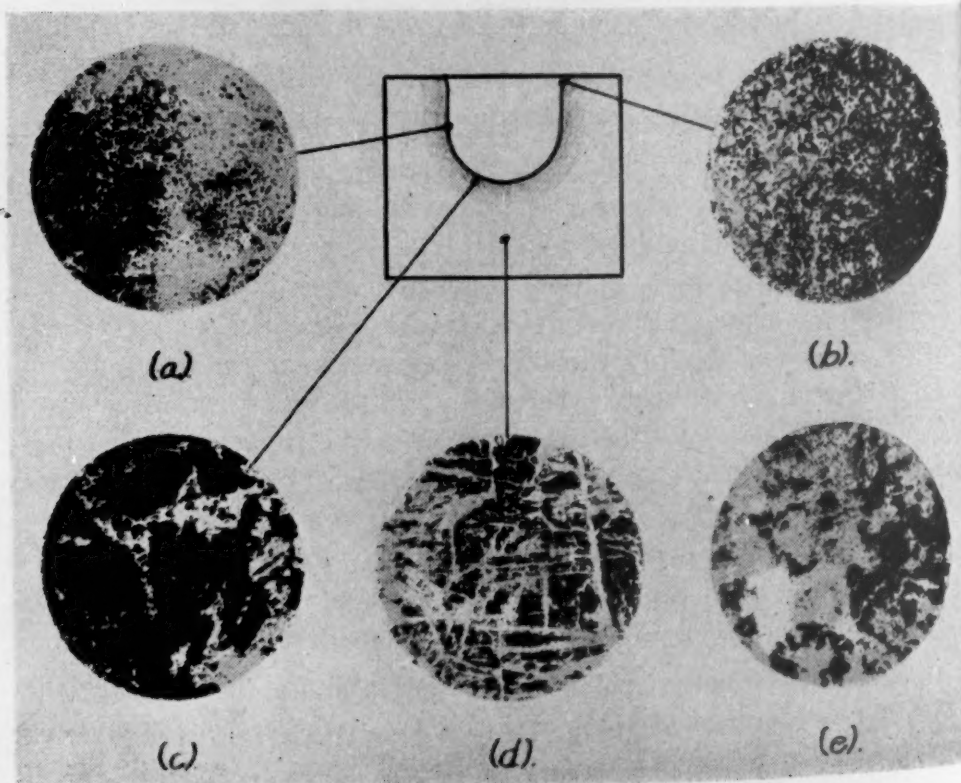


Fig. 3—Typical Photomicrographs of Weld Specimens from Block A, Plain Carbon Steel Welded in "As Cast" Condition. 150 Diameters (Reduced 1/3 in printing), Nital Etch. (a) Weld junction refined zone, (b) Weld junction, final pass, (c) Heat-affected zone, (d) Parent metal, "as cast", (e) Parent metal annealed at 1650°F. subsequent to welding.

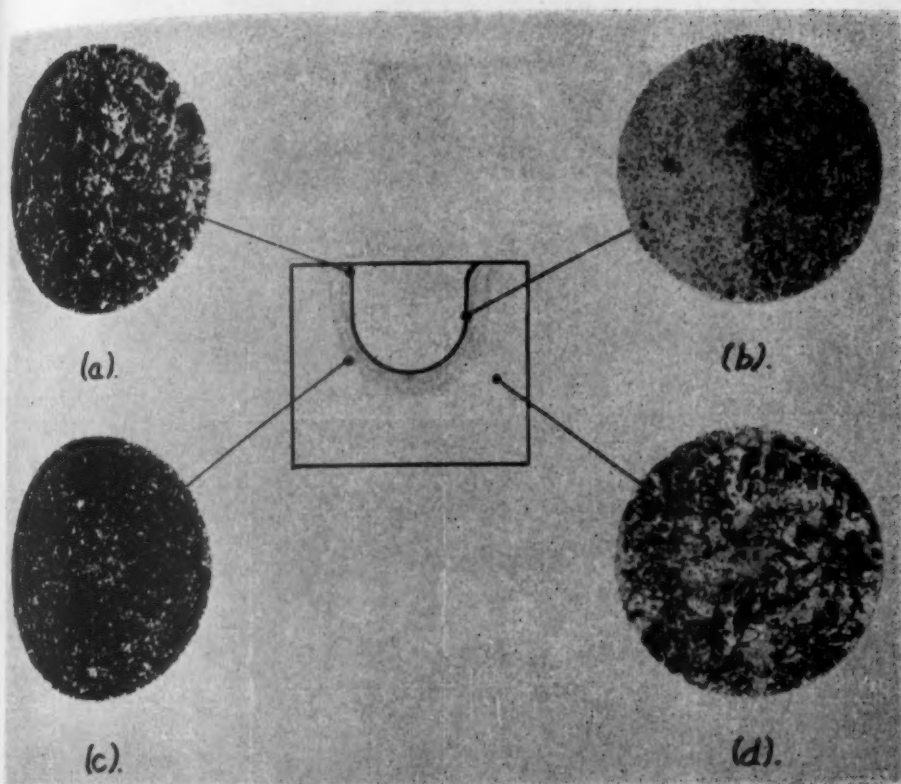


Fig. 4—Typical Photomicrographs of Weld Specimens from Block B, Plain Carbon Steel Casting Fully Annealed Before Welding. 150 Diameters (Reduced 1/3 in printing). Nital Etch. (a) Weld junction, final pass, coarse zone, (b) Weld junction, refined zone, (c) Heat-affected zone showing refinement, (d) Parent metal fully annealed.

duce welds, using the proper technique, having mechanical properties equal to that of the parent metal.

Photomicrographs

38. The photomicrographs shown in Fig. 3 are typical of the structures found in the four weld specimens cut from block "A". The parent metal shows the common Widmanstätten structure found in cast hypo-eutectoid steel. The partial refinement of this structure due to the heat effects of the multiple pass weld is shown in (a) and (c) which can be compared to (e) which shows the parent metal structure after annealing subsequent to welding. The refinement of weld metal due to following passes may be noted in (a) and (b) where (b) was taken in the final bead and thus shows the coarser grained weld metal.

39. No detrimental effects of welding on the "green" casting could be detected. The block being large we might expect the in-

ternal shrinkage stresses due to cooling to be high which could cause cracking but none was observed.

40. Figs. 4 and 5 are photomicrographs of the welds made on the annealed castings at room temperature and 300°F. respectively. No definite effects of the preheat could be observed in the structures which bears out the observations of hardness previously noted. The parent metal structures in the heat-affected zone are pearlitic indicating the complete transformation of austenite occurred at relatively high temperature. Fig. 5 (e) shows the effect of high temperature near the weld interface which causes austenitic grain growth while (c) shows refinement of grain compared to the parent metal (d). The coarse grained structure accounts for the increase in hardness near the weld.

41. Annealing subsequent to welding removed all differences in structure between the heat-affected zone and unaffected parent metal.

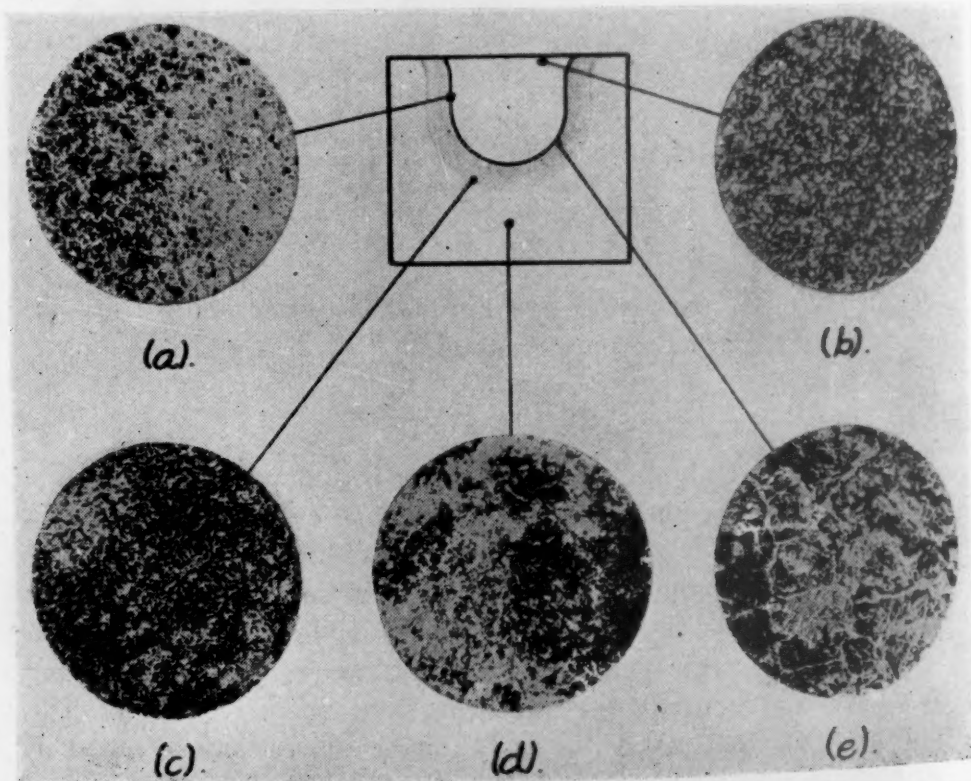


Fig. 5—Typical Photomicrographs of Weld Specimen from Block C, Plain Carbon Steel Fully Annealed, Welded at 300°F. Preheat. 150 Diameters (Reduced 1/8 in printing), Nital Etch. (a) Weld junction, refined zone, (b) Weld metal "as deposited," final pass, (c) Heat-affected zone showing refinement, (d) Parent metal, (e) Heat-affected zone showing coarsening.

42. There was no noticeable difference in the micro-structures of the various weld metals.

EXPERIMENTAL RESULTS MANGANESE-MOLYBDENUM STEEL

43. The manganese-molybdenum cast steel presents a much different picture than the plain carbon steel, the effects of welding being multiplied many fold due to the increase in carbon and manganese content and addition of molybdenum.

44. Castings of this analysis have definite air hardening properties and require special welding technique to produce satisfactory welds free of defects as shall be observed.

45. Another problem, from the practical viewpoint, is to obtain a weld that has mechanical properties equal to that of the parent metal in the various heat treated conditions in which it is used. In some instances, such as on wearing surfaces, it is desirable to have the hardness of the weld metal, after heat treatment, approximate that of the casting while generally the yield strength and ductility should be equivalent to that of the parent metal.

46. The electrodes selected were believed to be suitable for purposes of this investigation being typical of good commercial grades of plain molybdenum and low alloy chrome-nickel-molybdenum welding rods.

47. The chemical analysis of the deposited weld metal is given in Table 7.

Table 7

CHEMICAL ANALYSIS OF DEPOSITED WELD METAL

Electrode Designation	Per cent								
	C.	Si.	Mn.	P.	S.	Cr.	Ni.	Mo.	V.
73	0.10	0.090	0.46	0.020	0.010	—	—	0.51	—
100	0.10	0.200	0.46	0.027	0.077	0.41	1.00	0.54	0.02

48. Radiographs of the welds in the manganese-molybdenum steel revealed the following: Block 1, welded at room temperature with no subsequent heat treatment, shows severe cracking in all four welds. Blocks 2 and 3 which were welded at 300°F. and 600°F., respectively, and allowed to cool in air to room temperature showed scattered moderate cracking. Blocks 4 and 5 which were welded at 300°F. and 600°F., respectively, followed immediately

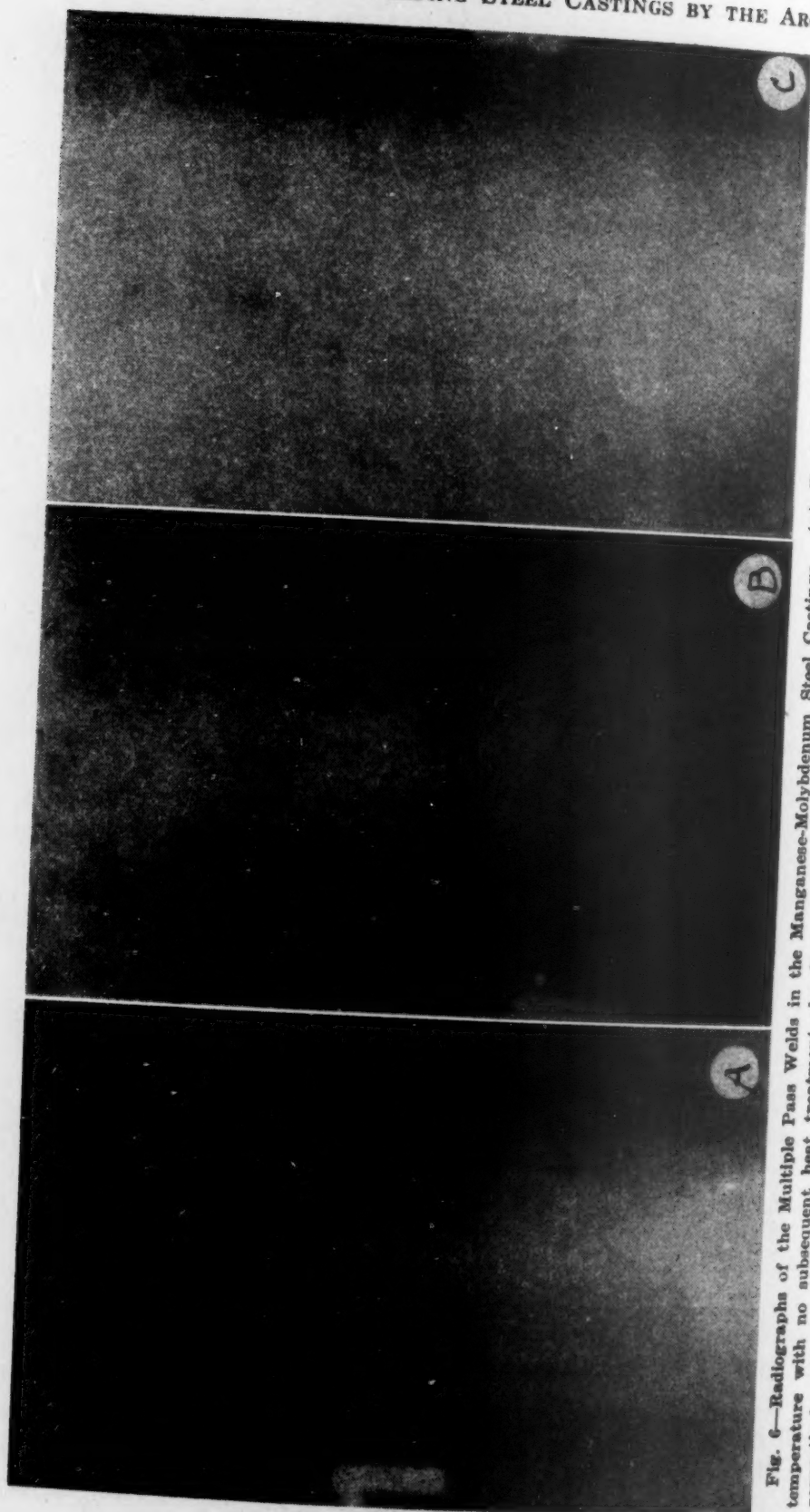


Fig. 6—Radiographs of the Multiple Pass Welds in the Manganese-Molybdenum Steel Castings. (a) Typical weld from block 1 welded at room temperature with no subsequent heat treatment showing severe cracking. (b) Typical weld from blocks 2 and 3 welded at 300° F. and 600° F. respectively, with no subsequent heat treatment showing moderate cracking. (c) Typical weld from blocks 4 and 5 welded at 300° F. and 600° F. respectively, and immediately stress relieved at 1200° F. showing no cracking.

by stress-relief at 1200°F. showed no evidences of cracking in any of the welds.

49. Negative prints of portions of the radiographs showing typical welds for each group of blocks are shown in Fig. 6. On casual examination one might be led to believe the cracks shown are in the weld metal. That this is not the case is evidenced by Fig. 7 which is a macrograph of a typical crack. The x-rays were taken normal to the top surface of the blocks (and welds) which accounts for the illusion.

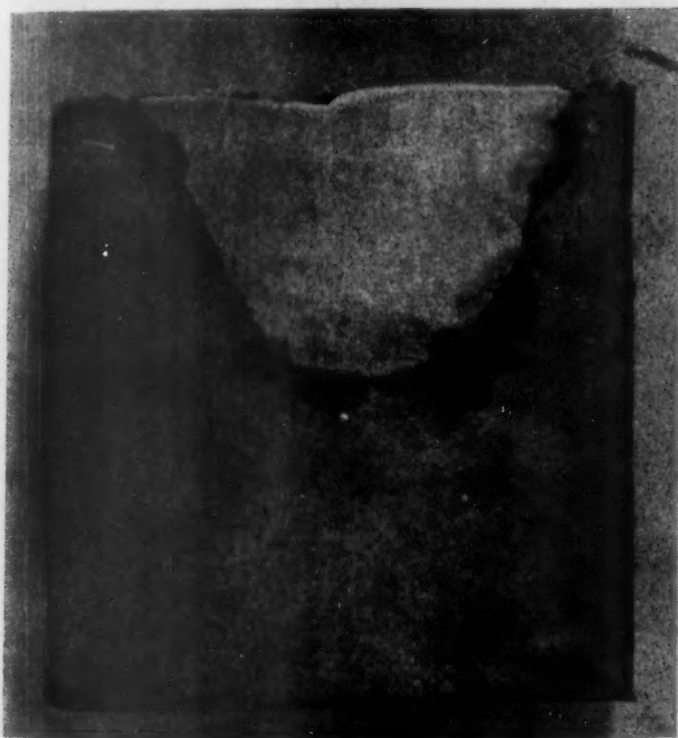


Fig. 7—Macro Section of Weld Showing Typical Cracks in Heat-Affected Zone, Specimen No. 13. Ammonium Persulfate Etch, X1.5.

50. The macrograph reveals numerous small cracks most of which, it may be noted, originate at the junction of a weld layer or pass with the parent metal. These extend downward into what we will later see is the most hardened part of the heat-affected zone. There can be little doubt but that the undercutting of each pass in welding, irrespective of how slight it may be, causes a concentration of the shrinkage stresses due to cooling and that this "notch effect" is a contributing factor to the cracking.

51. The effect of rate of heat input and cooling rate on the

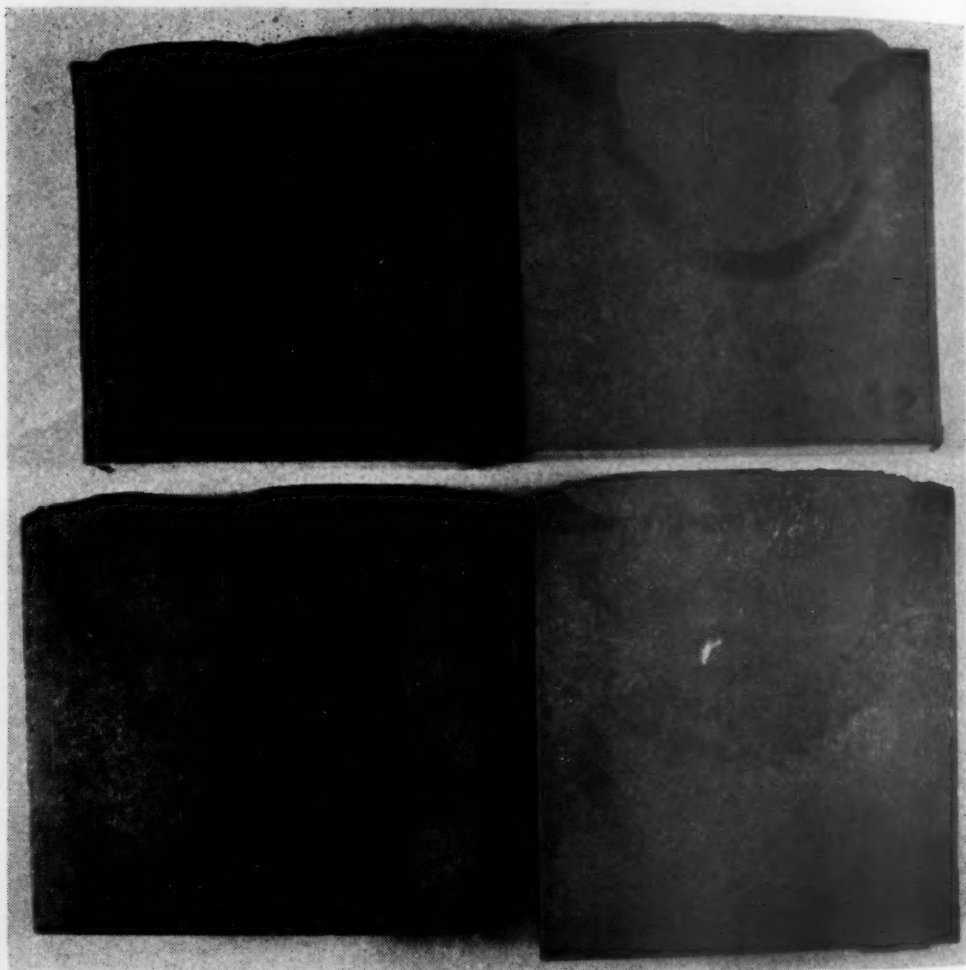


Fig. 8—Macro Section of Welds Showing Effect of Rate of Heat Input and Cooling Rate on the Width of the Heat-Affected Zone. Ammonium Persulfate Etch. (11) Welded at room temperature with 3/16" electrodes, current approximately 190 amperes. (12) Welded at room temperature with 1/4" electrodes, current approximately 280 amperes. (22) Welded at 300°F. preheat with 1/4" electrodes, current approximately 275 amperes. (32) Welded at 600°F. preheat with 1/4" electrodes, current approximately 230 amperes.

width of the heat-affected zone has not been brought out in any of our discussion thus far.

52. Preheating widens the heat-affected zone, that is, the region whose temperature rose above the critical range is extended farther into the parent metal away from the weld¹⁰. This effect is clearly shown in Fig. 8 between macrographs of specimens 11, 22 and 32 which were welded at room temperature, 300°F. and 600°F., respectively. Another effect of preheat which might be mentioned here is, that due to the higher temperature and less rapid dissipa-

¹⁰ Henry, O. H., and Claussen, G. E., *Welding Metallurgy*, American Welding Society, (1940), p. 327.

tion of heat, as preheat is increased, the welding current must be decreased. This is a matter of operators' welding procedure for the molten puddle will become excessively large and penetration too deep with the high rate of heat input as represented by high current.

53. The effect of rate of heat input is shown by macrographs of specimens 11 and 12 which were both welded at room temperature. Specimen 11 was welded with 3/16-in. electrodes and approximately 190 amperes average current while for 12 the rod used was 1/4-in. and current 280 amperes. With the greater heat input the block is also preheated by previous beads to a greater degree so the temperature gradient is less and the heat-affected zone widened.

54. The macrographs in Fig. 8 also show how the increased temperature due to greater heat input or preheat, as the case may be, causes a coarsening of the grains in the final weld pass, also how subsequent layers refine the grain of previous ones.

Hardness Surveys

55. The hardness surveys on welds in the manganese-molybde-

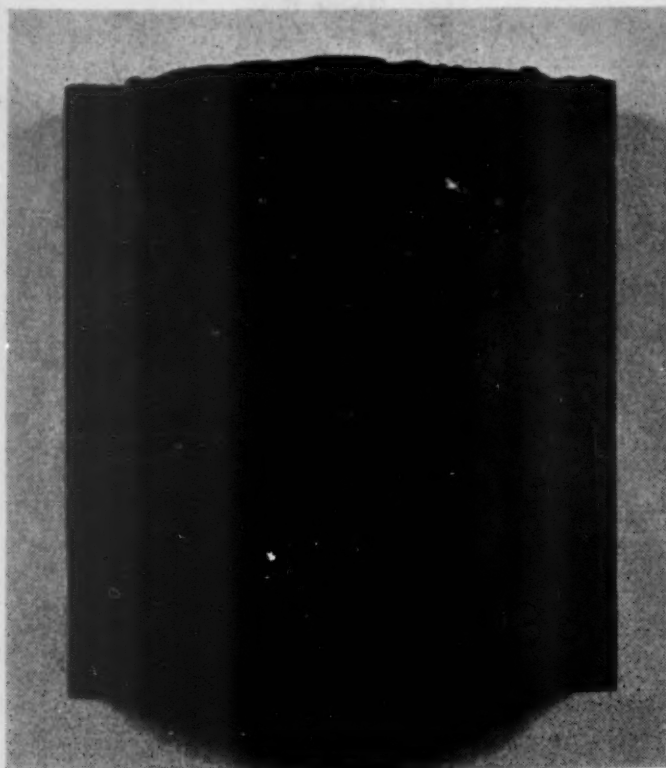


Fig. 9—Typical Weld Specimen Showing Hardness Survey.

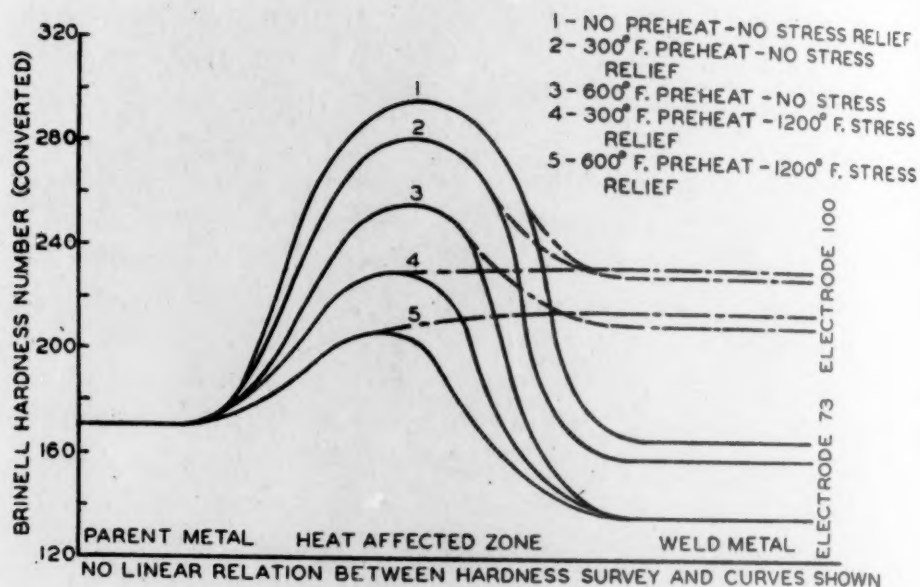


Fig. 10—Comparative Hardness Curves Showing the Effect of Preheat and Stress Relief on Welds in the Manganese Molybdenum Steel Castings.

Table 8

HARDNESS SURVEY OF MANGANESE-MOLYBDENUM STEEL CASTINGS

Block Designation and Condition for Welding	Welding Electrode	Hardness—Rockwell "B"		
		Parent Metal Range	Weld Metal Range	Heat Affected Zone Max.
1 No Preheat No Subsequent Heat Treatment	3/16-in. 73 1/4-in. 73 3/16-in. 100 1/4-in. 100	85-87	86-88 88-87 98-100 95-98	107 106 106 105
2 300° F. Preheat No Subsequent Heat Treatment	3/16-in. 73 1/4-in. 73 3/16-in. 100 1/4-in. 100		82-86 88-87 97-99 97-99	108 106 104 104
3 600° F. Preheat No Subsequent Heat Treatment	3/16-in. 73 1/4-in. 73 3/16-in. 100 1/4-in. 100		75-77 77-79 94-98 94-96	103 102 103 102
4 300° F. Preheat 1200° F. Stress Relieve 1 Hr. Per Inch	3/16-in. 73 1/4-in. 73 3/16-in. 100 1/4-in. 100		78-81 74-77 97-100 96-100	98 98 98 96
5 600° F. Preheat 1200° F. Stress Relieve 1 Hr. Per Inch	3/16-in. 73 1/4-in. 73 3/16-in. 100 1/4-in. 100	85-87	74-76 77-82 94-97 95-97	95 95 94 95

num steel castings bring out certain facts not discussed under plain carbon steels. This is due to surveys being made of single pass as well as multiple pass welds under various welding conditions.

56. Figure 9 is a macrograph of a typical multiple pass weld specimen showing locations where hardness readings were taken. It should be noted that this specimen was welded at 600°F. preheat so has a relatively wide heat-affected zone. In the narrower zones the hardness impressions were, of necessity, closer as in all cases three readings were taken across the zone.

57. In the multiple pass welds Rockwell "B" readings were taken while in the heat-affected zone of the single bead welds it was necessary to use Rockwell "C". All were converted to Brinell hardness numbers for uniformity in plotting curves and comparison.

58. Table 8 summarizes the results of surveys on the multiple pass welds and these have been plotted to show the trends in Fig. 10. The effect of preheat and stress-relief on the maximum hardness in the heat-affected zone is clearly shown and the reasons for the reduction in hardness explained in the fundamental discussion.

59. The wide range in hardness of weld metal obtainable with different welding electrodes should be observed; also that the type or size of rod used, within the limits of this investigation, has no effect on the maximum hardness obtained in the heat-affected zone.

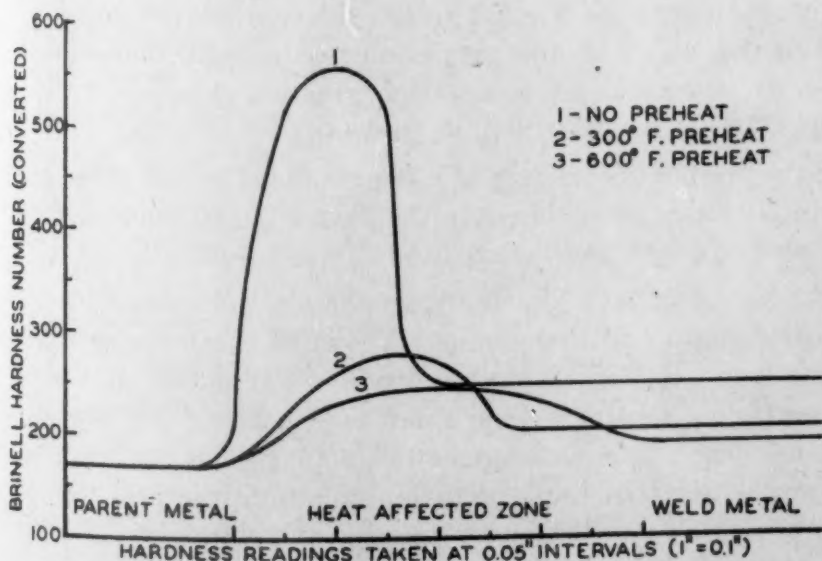


Fig. 11—Hardness Curves Showing the Effect of Preheat on Single Pass Welds on the Manganese-Molybdenum Steel Castings.

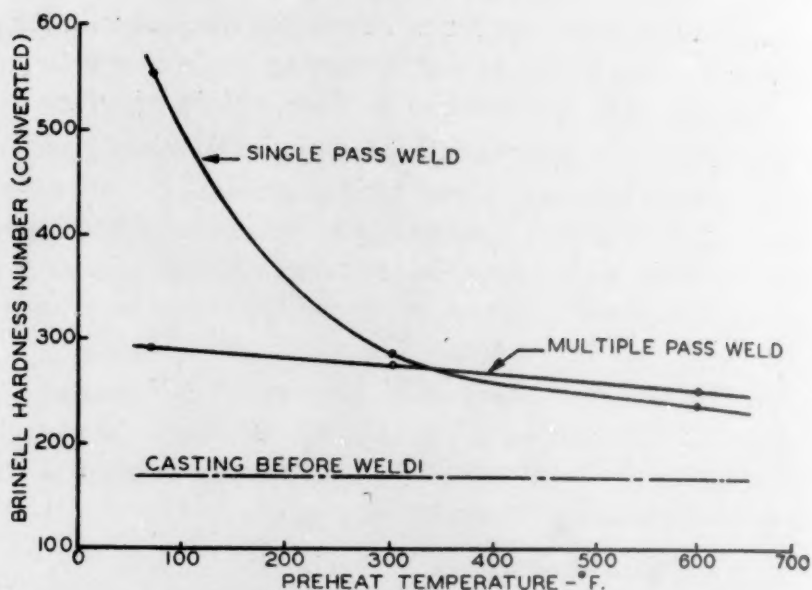


Fig. 12—Effect of Preheat on the Maximum Hardness Obtained in the Heat-Affected Zone of the Manganese-Molybdenum Steel Castings.

60. The low alloy electrode designated (100) hardens measurably on stress relieving in contrast to the usual softening of plain carbon or carbon molybdenum rods. This is probably a precipitation hardening phenomenon.

61. Hardness readings on the single pass welds were taken at 0.05" intervals across each specimen. These were plotted to scale to give the curves of Fig. 11 which show clearly the effect of preheat on the width of, and maximum hardness in, the heat-affected zone. It is significant to note the greatest effect on softening is obtained from the first 300°F. preheat.

62. In order to compare at a glance the effect of preheat on the maximum hardness obtained in the heat-affected zones of the single pass and multiple pass welds Fig. 12 was prepared.

63. Note that from the curve for the multiple pass weld it would appear preheat had little value. That this is not the case is shown by the curve for the single pass weld where 300°F. preheat drops the maximum hardness from about 560 to below 300 Brinell hardness number. This emphasizes the point which has been brought out previously that the structure of the multiple pass weld should not be used as a criterion for judging the suitability of a welding procedure or the weldability of a metal.

64. The annealing effect of subsequent passes is shown by these

curves and will be discussed further in connection with the photomicrographs.

65. One would expect to find the curve for the multiple pass weld always below that of the single pass weld until they met at a temperature where the base metal was austenitic. The fact that the curves cross is of no significance as the difference in hardness necessary to change this relationship is well within the probability of error in accuracy of hardness readings, preheat temperature measurements and the like.

66. Fig. 13 is of interest more from the practical than metallurgical standpoint. It shows the hardness of the parent and weld metals after various heat treatments. The precipitation hardening effect in electrode 100 is again apparent.

67. The curves are of value in selecting an electrode to match the mechanical properties of the parent metal in the particular heat treated condition in which it is to be used. The limiting hardness obtainable in the weld metal for the electrodes used is 240 Brinell hardness number which is about the maximum hardness at which this type of casting is used commercially.

Photomicrographs

68. It has been shown how welding increases the hardness of the parent metal adjacent to the weld and in some instances causes

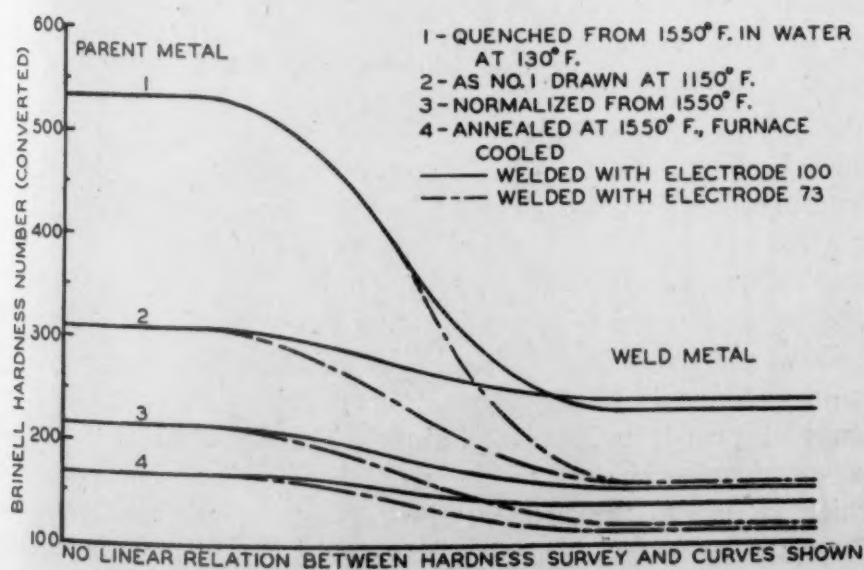


Fig. 13—Effect of Various Heat Treatments on the Hardness of the Welded Manganese-Molybdenum Steel Castings.

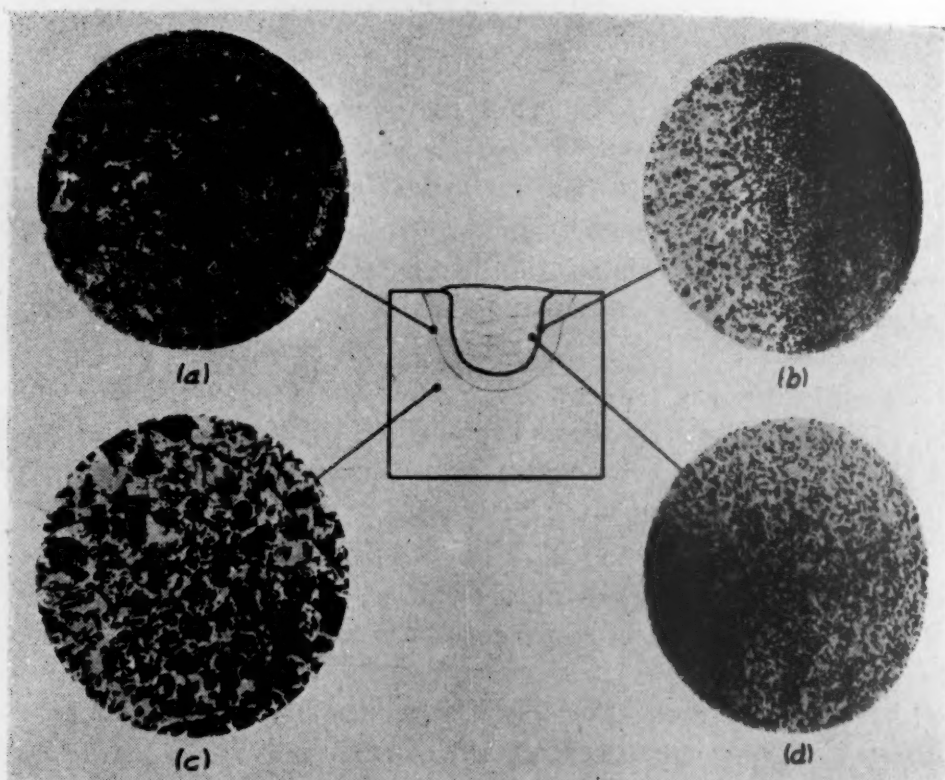


Fig. 14—Photomicrographs of Typical Structures of the Multiple Pass Welds in Block 1, Manganese-Molybdenum Steel, Welded at Room Temperature, No Subsequent Heat Treatment. 150 Diameters (Reduced 1/3 in printing), Nital Etch. (a) Transition zone between heat-affected and parent metal, (b) Weld junction, (c) Unaffected parent metal, (d) Weld metal taken at junction of two passes.

cracking to occur. Let us now consider the changes in structure due to the heat effects of welding on the low alloy steel casting under investigation.

69. Fig. 14 shows typical structures found in the welds in Block 1. The parent metal shows good refinement and is the usual structure found in this steel. The structure shown in view (a) is in a zone that was not heated sufficiently high in welding to become fully austenitic and may be termed the transition zone. The weld metal (d) is taken at a junction between two passes and since it shows no columnar grains indicates the heat from subsequent passes completely recrystallized the previous beads. This is evidence of proper welding technique. The junction (b) shows the parent metal adjacent to the weld interface to be fine grained which is due to the heat-treating effects of the multiple passes. These structures are typical of those observed in the other multiple pass weld specimens the effects of preheat not being discernible at lower magnifications.

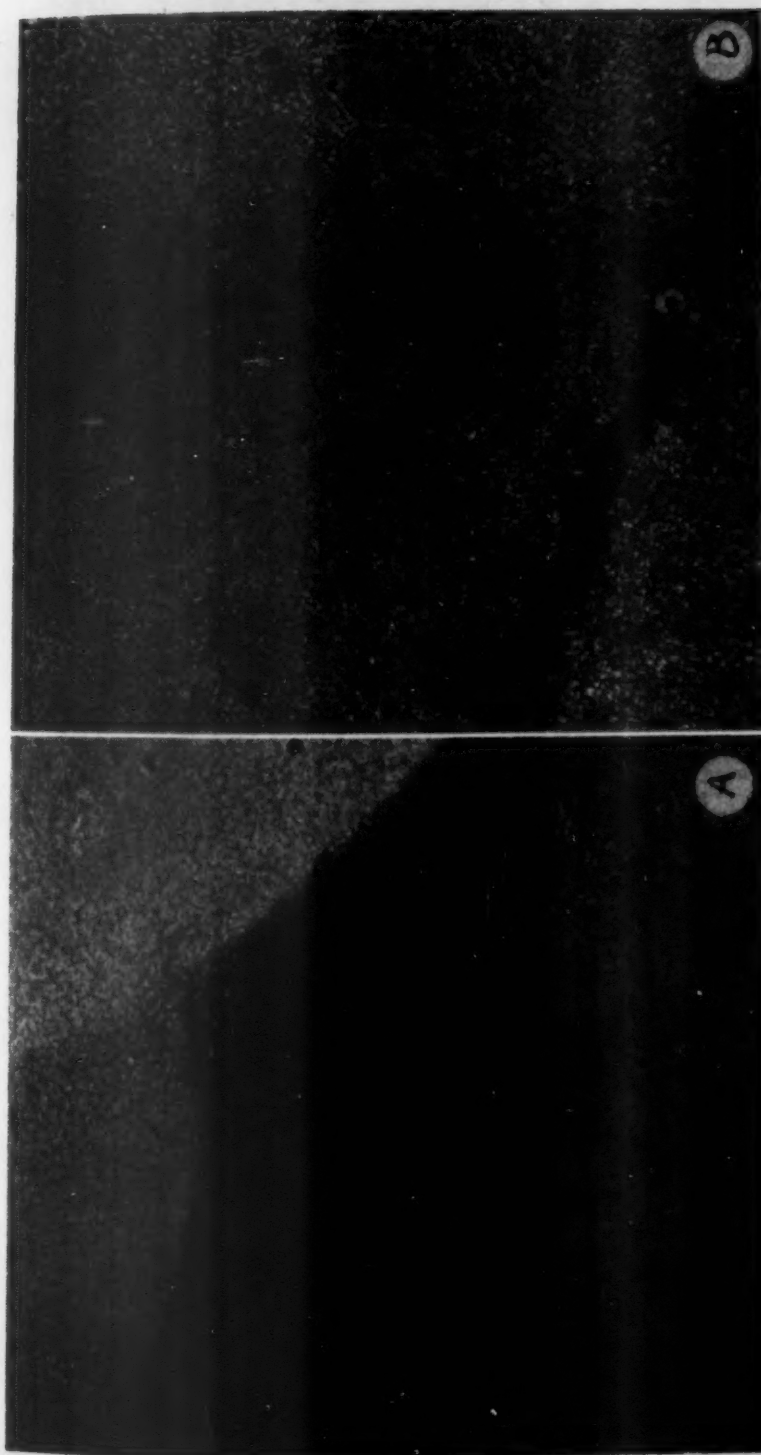


Fig. 15—Photomicrographs Showing Typical Cracks in the Heat-Affected Zone of the Manganese-Molybdenum Steel Casting Welded at Room Temperature With No Subsequent Heat Treatment. (a) 50 Diameter, Nital Etch, (b) 150 Diameter, Nital Etch.

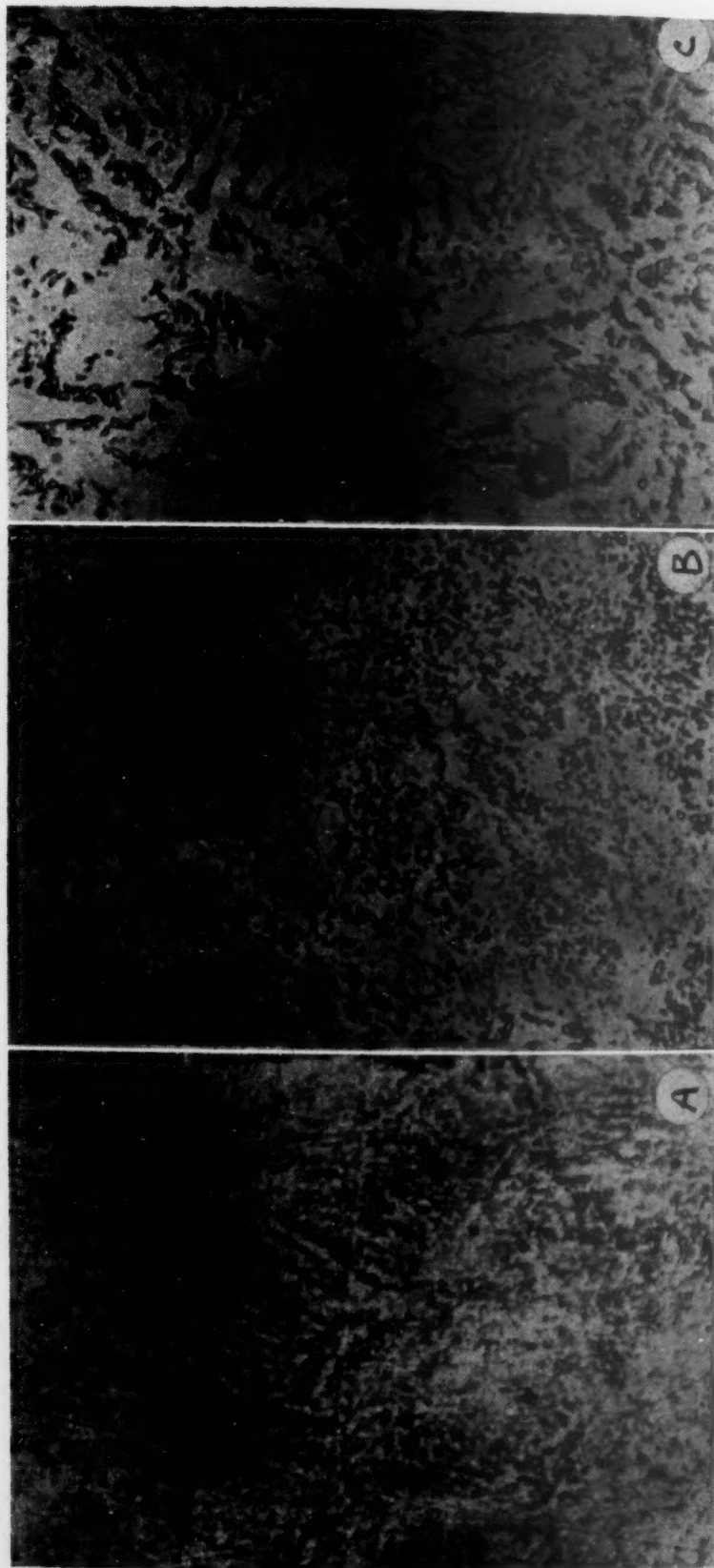


Fig. 16—Photomicrographs of the Heat-Affected Zone in the Multiple Pass Welds in the Manganese-Molybdenum Steel Castings. 1000 Diameters, Picral Etch. (a) No Preheat, No Subsequent Heat Treatment, (b) 300°F. Preheat, No Subsequent Heat Treatment, (c) 600°F. Preheat, No Subsequent Heat Treatment.

70. We have previously discussed the origin and location of cracks of which radiographs and macrographs were shown. Figure 15 (a) shows the origin of a crack at the junction of two passes which are clearly shown. The "notch effect" and concentration of stresses at the edge of each layer are contributing factors in cracking but the underlying cause is the brittle microstructure adjacent to the weld. This structure is shown in Fig. 15 (b) at 150 diameters which also shows two cracks that paralleled the weld interface in this hardened zone.

71. Figure 16 shows the microstructure of the hardened zone in multiple pass welds made with similar procedure except for varied preheat. The structure in (a) is pearlitic as would be obtained as a result of slow transformation. This structure is explainable in a multiple pass weld where subsequent beads arrest the cooling as was noted in Fig. 1. View (b) shows finely spheroidized pearlite due to the continued heating just below the critical as a consequence of multiple passes. View (c) is essentially the same structure with enlarged carbides due to higher preheat.

72. This growth of the carbides accounts for the relatively lower hardness observed for the welds made at 600°F. preheat. It will be recalled, however, that the effect of preheat on hardness noted in the heat-affected zone was far greater in the case of the single pass welds.

73. Consideration should now be given to the single bead welds which were made at room temperature, 300°F. and 600°F. so as to be comparable to the multiple pass welds.

74. Early in this paper the effects of carbon, manganese and molybdenum on the transformation characteristics of steel were mentioned. Broadly speaking, they act to delay the conversion of austenite so that after the steel has cooled below the "nose" of the S-curve, as alloy content increases, the temperature at which transformation takes place decreases.

75. It is apparent from Fig. 17 (a) that due to the fast cooling rate in welding without preheat martensite formed. The martensite was found to be very coarse grained under low magnification. You will note that the weld cracked in this structure even tho the weld was a single surface bead where there was little restraint and one might expect comparatively low shrinkage stresses. Fig. 12 shows the hardness to be about 560 Brinell in this zone.

76. Photomicrograph (b) shows the acicular structure of mar-

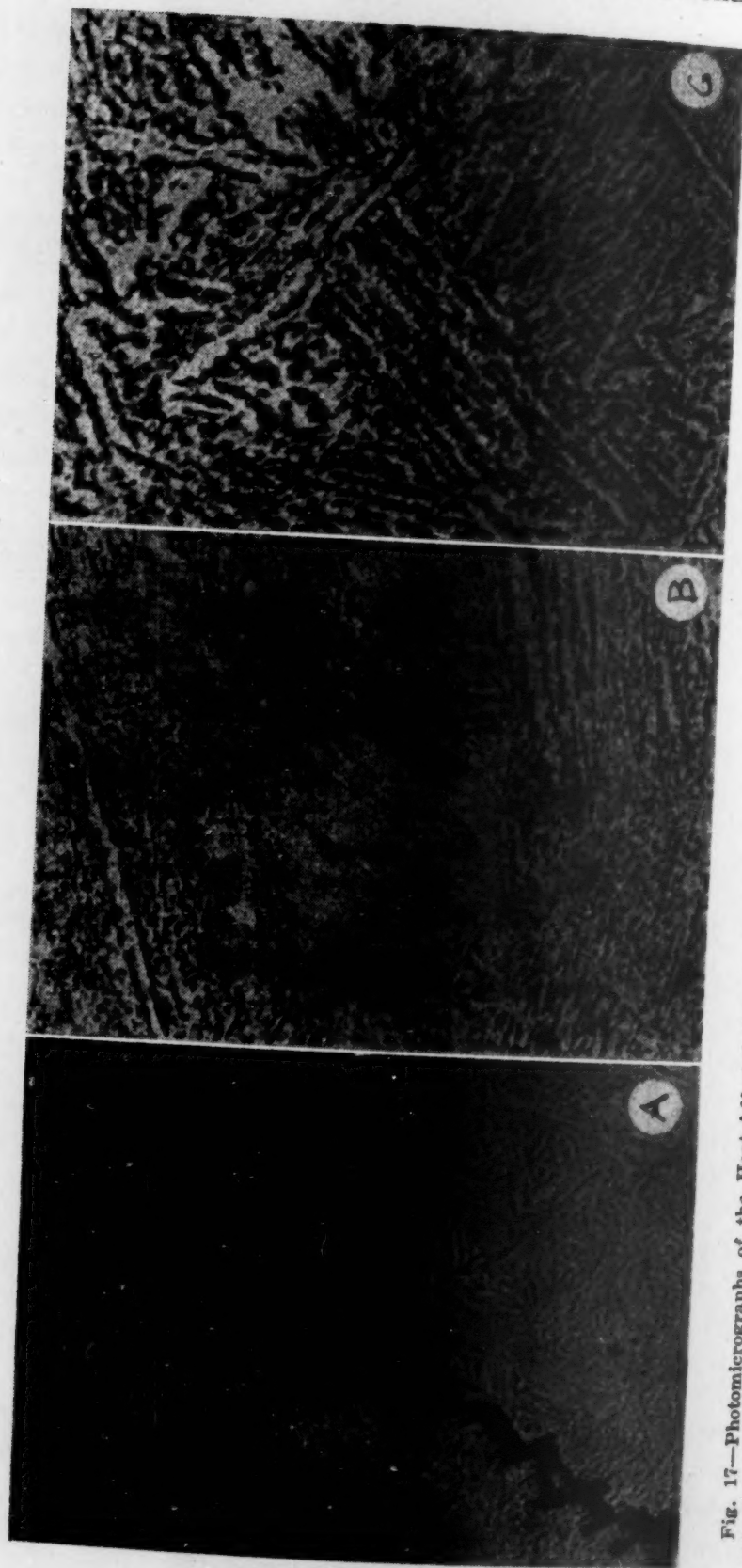


Fig. 17—Photomicrographs of the Heat-Affected Zone in the Single Pass Welds on the Manganese-Molybdenum Steel Castings Showing the Effect of Preheat. 1000 Diameters, Pical Etch. (a) No Preheat, (b) 300° F. Preheat, (c) 600° F. Preheat.

tensite coarsened due to preheat, the transformation being completed at a higher temperature. A still coarser yet acicular structure is observed in (c) due to the still higher transformation temperature. No cracks were detected in the single pass welds made at 300°F. and 600°F. indicating this structure to be more ductile than the fine martensite observed in the weld specimen made at room temperature. This is borne out by the decrease in hardness which may best be noted by referring back to Fig. 12.

CONCLUSIONS

77. Within the limits of this investigation the following conclusions may be drawn:

- (1) The casting stresses and segregation have no detrimental effects on the weldability of plain carbon steels "as cast."
- (2) No preheat is necessary for the satisfactory welding of plain carbon steel castings having a carbon content not exceeding 0.35 per cent associated with 0.60 per cent manganese. However, subsequent stress-relief or full anneal is desirable.
- (3) Preheat is essential for the satisfactory welding of manganese-molybdenum steel castings having a carbon content of 0.35 to 0.40 per cent associated with 1.25 to 1.50 per cent manganese and 0.20 per cent molybdenum. However, preheat alone is not sufficient to eliminate cracking in the structure adjacent to the weld but welding must be followed immediately by stress relieving to assure absence of such defects.
- (4) In the welding of castings, due to the high degree of restraint, shrinkage stresses are high and extraordinary precautions are necessary to avoid brittle martensitic structure (and consequential cracks) which cannot be removed by subsequent treatment.
- (5) The effect of preheat on the maximum hardness in the heat-affected zone is far more effective for the lower temperatures than higher, and decreases with increased temperatures. Therefore, little is gained by 600°F. preheat over 300°F.
- (6) The size or type of welding electrode has no effect on

the maximum hardness created in the heat-affected zone due to welding.

- (7) Increase in the size of electrode (rate of heat input) or preheat temperature results in a widening of the heat-affected zone.

78. In the investigation of weldability of steels or suitability of welding procedures, a hardness study is a valuable adjunct to the microscopic examination. However, no such investigations should be made without including single pass welds since results obtained from multiple pass welds alone tend to be misleading.

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DISCUSSION

Presiding: H. D. PHILLIPS, Lebanon Steel Foundry, Lebanon, Pa.

Co-Chairman: R. A. GEZELIUS, General Steel Castings Corp., Eddystone, Pa.

T. N. ARMSTRONG¹ (*written discussion*): The authors are to be complimented for such a well prepared paper and for the concise manner in which they have presented their findings. It is believed that there is some question as to whether sulphur up to 0.05 per cent may not be considered detrimental. This is not the authors' deduction but is taken from one of the references which they cite. The question is raised as it has been definitely determined that manganese on the high side in cast steel will not always render sulphur harmless. Under certain conditions network sulphides occur which have low melting points and it is quite possible that cooling stresses that occur after welding will cause cracking along these grain boundary non-metallic inclusions.

¹ International Nickel Co., New York, N. Y.

In paragraphs 60 to 67, the authors attribute increase in hardness, after stress relieving of deposits made with electrode 100, to precipitation hardening phenomenon. While it is admitted that steels of this type may be subject to some hardening by precipitation, it is believed that a temperature of 1200°F. is sufficiently high to cause overaging which would wipe out the evidence of precipitation hardening. It is believed that a more logical explanation might be that the stress relief temperature is sufficiently high to exceed the transformation temperature. Some of the nickel-chromium-molybdenum steels have comparatively low temperatures of transformation and in some instances it has been found to be below 1200°F.

L. C. HOST² (*written discussion*): The authors of this paper are to be congratulated on furnishing such valuable data on preferable welding methods applied to steel castings. To those of us in the marine field the data on plain medium carbon steel castings are particularly reassuring, as welding repairs to the large castings forming part of a ship are often necessary at some stage of her life. Preheat or post-heat treatment is usually impracticable to these medium steel castings whose physical properties are usually governed by the ship classification societies of the principal maritime countries. I think it is fortunate that the requirements of these organizations call for an upper tensile strength limit of around 78,400 lb. per sq. in. which automatically keeps the carbon no greater than the early thirties which the authors show can be welded with minimum risk without preheat or post-heat treatment.

C. L. FREAR³: I am pleased to see a paper on welding of castings presented before the AMERICAN FOUNDRYMEN'S ASSOCIATION, as I am a strong advocate of welding, not only to repair accidental or inherent defects but for simplifying the foundry procedure in the production of castings. In the latter case, the Bureau of Ships has often recommended making a complicated casting in two or more parts, each of which can be produced by ordinary steel foundry methods and then assembling these pieces into a single unit by welding. The Navy has followed improvements in welding technique with continual reductions in its specification requirements with regard to the welding of steel castings.

CHAIRMAN PHILLIPS: This paper further demonstrates the value of X-ray or radiographic examinations. I have had the experience many times of going into the cleaning room and talking to the welding supervisor or cleaning room foreman about welding certain low alloy steel castings and have had them tell me that it is a perfect job and that they did not have to preheat or give a stress relief treatment. To the eye or surface examination, that looks to be the case, but under X-ray examination, defects quite often show up.

MEMBER: Have you ever had occasion to exceed 600°F. preheat?

MR. MUELLER: We found very definitely that above 600°F., even above 300°F., there were no increases in the suitability of the welding sufficiently serious to warrant a higher preheat. The 300°F. preheat

² American Bureau of Shipping, Cleveland, O.

³ Bureau of Ships, Navy Dept., Washington, D. C.

will do just as much for refining your structure in the heat-affected zone as will the 600°F. preheat.

MEMBER: In our foundry, on a 0.50 per cent carbon steel, we were having trouble with porosity in our welds and we could not find a suitably coated rod. Our customer insisted upon our using a certain bare rod which we could not do at any preheat we were using up to 600°F. without getting a certain amount of porosity in our weld, no matter what procedure the welder used. After two or three weeks' study we decided to use the same rod and get a successful weld by playing a flame on the weld as it progressed through the crevice. We kept the casting at a temperature of approximately 1200°F., and then immediately drew it.

MR. MUELLER: Do you think it was a case of keeping your slag on top? You said the flame was right on the weld which would keep the slag more fluid.

J. A. DUMA⁴: In the welding of manganese-molybdenum steels, our experience with them parallels yours in that they undergo pronounced grain coarsening in the heat-affected area immediately below the fusion line. One of the reasons why some of the commercial steels use vanadium in medium manganese steel is to refine that grain or inhibit grain growth. Yet, you say that with the use of preheat, grain coarsening in the base metal is inhibited or, as you put it, it is refined. I cannot see how that can happen, for it has been shown by good authority that both preheat and a high interpass temperature are conducive to grain growth. Another thing that surprises me is the fact that it was necessary to stress-relieve your weld immediately after welding to eliminate the possibility of cracking, even with the use of preheat. We, in our welding of steel, found that cracking occurred during the welding operation and very seldom subsequent to it. You may have an explanation for that.

MR. OESTERLE: In regard to the first question, there is no doubt that each successive pass heat-treats the previous pass. It is possible to have the base metal heated above the critical by the second pass and even the third pass. Each pass contributes to and helps control the rate of cooling. These steels are decidedly air hardening. Naturally, in order to obtain preliminary structures that are definitely softer and more spheroidized, it is necessary to obtain the proper cooling rate. There were no indications, in our work, that cracking occurred during welding, but we are sure that welding set up a very high stress gradient. If the structure resulting from welding is not sufficiently ductile to withstand this stress, you will have cracking. I believe that we definitely proved that the martensitic structure obtained by rapid cooling in the single pass weld was not sufficiently ductile to absorb cooling stresses, and that cracks were, therefore, obtained in it.

H. R. MCCOY⁵: I believe the point which Mr. Oesterle has just made is often overlooked, namely, rate of cooling. Drastic cooling of the weld is prevented when the castings are put into the draw furnace immediately after welding, thus preventing the formation of the brittle constituent,

⁴ Norfolk Navy Yard, Portsmouth, Va.

⁵ Ohio Steel Foundry Co., Lima, Ohio.

martensite. We found that we could get around the tendency for too rapid cooling by running the castings through an insulated hood placed over the conveyors in the production line just beyond the welding station.

We preheat our castings to 300°F. and 350°F. They are from 2- to 3½-in. in cross-sectional area and hold the heat fairly well until after welding is over. Then, instead of giving them an immediate stress-relief draw we use the "thermos-hoods," and the material cools down at a retarded rate. Our radiographs do not show any cracks.

Of course, if the carbon and manganese are both on the high side of the range of the analysis covered by the speaker, care must be exercised because that is the border-line. However, we have lowered our range to 0.28-0.32 carbon, 1.00-1.20 manganese and 0.35-0.40 molybdenum, and we find that we can avoid cracking in castings of the cross-section stated.

Any one can make a good weld and then spoil it by too rapid cooling of the weld, particularly in the winter time.

After we take the castings through the "thermos-hood," they are held until such time as the stress-relieving furnaces are available, and then they are given the regular stress relief. In other words, we are not substituting the "thermos-hood" idea for the stress relief but merely preventing cracks in welds by slow-cooling after welding.

Another method for preheating which works on larger castings is to place them on steel grills or gratings built over a coke or charcoal fire. They are tested with a thermometer, and when they are up to 300°F. they are removed, welded and immediately returned to a spot on the grill where they can cool down slowly or be held for a time at around 300°F. until the weld has cooled slowly to about 300°F. Then they can be removed.

MR. MUELLER: We find the same thing to be true with our carbon running between 0.32 to 0.35 per cent and our manganese 1.25 to 1.40 per cent. We find that by slow cooling, even in gas-cutting our heads, we keep the casting warm and give it a stress relief anneal.

MR. MCCOY: I would recommend the immediate stress relief as the proper method. However, in a great many shops, with the present production rate, a stress relief furnace is not available immediately for the castings. Another bad thing is that our men in the shop, at times, have been rushed to the point where they want to do their welding before the initial heat treatment. In spite of all that can be done, if a radiograph or gammagraph is run on the castings, invariably checks will be found. From a distortion standpoint, I think it is a bad thing to do any welding on a casting before it has had an initial dendrite break-up treatment, even a carbon steel casting.

CHAIRMAN PHILLIPS: It is very interesting to get actual shop practice confirmation with respect to manganese-molybdenum steel.

P. G. DEHUFF, JR.⁶: Of course, you all realize that in the process of welding the steel casting is being poured into a chilled mold and, if the mold is not preheated, it will cause quite a lot of trouble.

At Lehigh, we are running a series of tests in an effort to tie together

⁶ Lehigh University, Bethlehem, Pa.

such variables as the preheat temperature, the stress relief, and the rate of power input. It is our hope to have some mathematical formulae or some tables whereby one can predict in advance the expected hardness in the heat-affected zone that will result from the variables just mentioned.

MESSRS. MUELLER, SMITH and OESTERLE (*authors' closure*): The authors wish to thank the gentlemen who discussed this paper for their remarks. We are especially appreciative of the remarks made by Chairman Phillips.

Mr. Mueller made reference to an iron oxide slag formed by oxidation when welding with a bare rod. This slag was perhaps not easily kept fluid and protective unless heated to the indicated temperature of 1200°F.

In reply to T. N. Armstrong's written discussion, we wish to say that we are in full accord with references cited on 0.05 sulphur limitation. We base our contention on the fact that both Navy and Army Specification Bureaus have approved a sulphur content of 0.06 for castings which are to be welded aboard ship without preheat or subsequent stress relief. It might also be stated that combined carbon is generally set at a maximum of 0.90 per cent. Even though this gives insufficient manganese to compensate for the sulphur, the sulphur is still harmless.

We agree that the double sulphide network is definitely a low melting point alloy and, therefore, has no alternative other than to precipitate in grain boundaries. Because of low strength at elevated temperatures cracks develop.

We are quite sure our temperatures did not exceed the critical transformation point. Because we had no explanation we consulted metallurgists in the welding field and concurred with them when they suggested precipitation hardening as the explanation.

The written discussion of L. C. Host is especially welcome since it develops an additional application.

The Effect of Copper Content and Low Temperature Pretreatment of Some White Irons on Malleableization

BY ARTHUR ELSEA*, AND C. H. LORIG**, COLUMBUS, O.

Abstract

The effect of copper content, of low temperature pretreatment, of heating rate, and of first stage holding temperature, on the malleableization rate of white cast iron was studied. The experimental work was conducted using white irons of almost identical compositions except for the copper content which varied from 0.03 to 2.48 per cent. The low temperature pretreatment consisted of holding the white cast iron at 600°F. for 8 hours prior to the usual malleableization treatment. The cycles studied consisted of a slow and a rapid rate of heating to two holding temperatures (1600°F. and 1700°F.), holding for the time required to effect complete decomposition of the massive carbides, and finally, uniform cooling to a temperature below the critical range at a rate which just produces fully ferritic structures. Microscopical examination of the resulting specimens showed the effect of the copper content and the various treatments on the malleableizing cycle and the microstructure. The combined effect of copper and preliminary treatment was to reduce drastically the size of the temper carbon nodules and to shorten the graphitizing time considerably.

1. Copper as an alloying addition in malleable cast iron has been widely discussed in the literature. In an iron of standard malleable composition copper accelerates graphitization^{1, 2}, reduces the graphite nodule size^{3, 4}, raises the yield point and the tensile strength^{5, 6}, makes possible a still further increase in strength by precipitation treatment, increases the corrosion resistance^{7, 8} in atmosphere and in certain corrosive media, and reduces the tendency toward galvanizing embrittlement⁹.

2. The work described in this paper was directed toward determining the effect of pretreatment, heating rate, and holding temperature on the malleableizing cycle and microstructure of white

* Research Metallurgist, and ** Supervising Metallurgist, Battelle Memorial Institute.

¹ The superior figures indicate numerical order of bibliography at end of paper.

NOTE: This paper was presented before a Malleable Session at the 46th Annual A.F.A. Convention, Cleveland, O., April 20, 1942.

cast irons of malleable iron composition containing various amounts of copper.

MATERIAL USED

3. The white cast irons used in the experimental work of this study were supplied by Yale & Towne Mfg. Co. in the form of standard cast tensile bars. Five groups of tensile bars were received all cast from the same melt, each group having a different copper content. Copper additions were made in the ladle. The compositions of the irons are given in Table 1.

Table 1
COMPOSITION OF WHITE CAST IRON TENSILE BARS

Bar No.	Copper, per cent	Carbon, per cent	Silicon, per cent	Manganese, per cent	Phosphorus, per cent	Sulphur, per cent
0	0.032	2.56	1.02	0.32	0.10	0.072
1	0.604	2.57	1.02	0.32	...	....
2	1.22	2.58	1.01	0.31	...	0.073
3	1.62	2.59	1.00	0.30	...	....
4	2.48	2.60	0.98	0.30	...	0.073

4. The microstructures of the bars in the as-cast condition are shown in Fig. 1. Bars Nos. 3 and 4 (D and E in Fig. 1) with 1.62 and 2.48 per cent copper, respectively, contained a few isolated areas of primary graphite; all other bars were completely white.

5. One half of the tensile bars of each group were given a preliminary treatment which consisted of holding at 600°F. for eight hours^{10, 11, 12}.

6. The grip ends, that is, the 3/4-in. sections of bars of each group, both with and without the pretreatment, were cut into specimens 7/8-in. long. Subsequent graphitization treatments were conducted by packing the specimens in small closed containers.

EXPERIMENTAL METHOD

Procedure Employed in First Stage Graphitization Tests

7. First stage graphitization tests consisted in determining, for a given heating rate and holding temperature, the minimum time that would produce specimens free from massive carbides.

8. Four series were run in the first stage graphitization study. They were as follows:

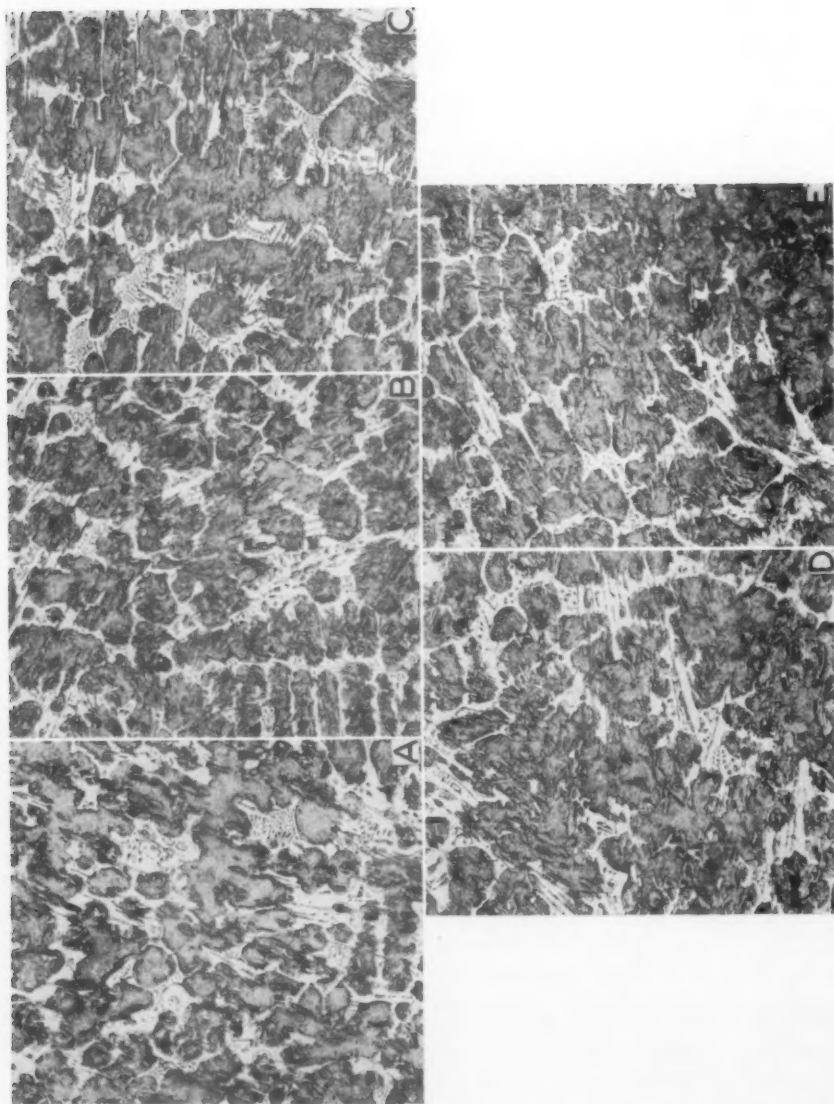


FIG. 1.—MICROSTRUCTURES OF AS-CAST TEST BARS CONTAINING VARIOUS PERCENTAGES OF COPPER. A—BAR NO. 0—0.03 PER CENT. B—BAR NO. 1—0.69 PER CENT. C—BAR NO. 2—1.22 PER CENT. D—BAR NO. 3—1.62 PER CENT. E—BAR NO. 4—2.48 PER CENT. ETCHED WITH PICHAL. 8100

Series 1. Specimens heated to 1600°F. in 40 minutes. Holding temperature 1600°F.

Series 2. Specimens heated to 1700°F. in 40 minutes. Holding temperature 1700°F.

Series 3. Specimens heated to 1000°F. in 1 hour, and from 1000 to 1600°F. in 6 hours. Holding temperature 1600°F.

Series 4. Specimens heated to 1000°F. in 1 hour, and from 1000 to 1700°F. in 6 hours. Holding temperature 1700°F.

9. In conducting the tests on first stage graphitization, specimens with and without the preliminary treatment were suitably packed, placed in an electric muffle furnace, and heated at the desired rate to a given holding temperature. At one hour intervals, after the specimens had reached the holding temperature, a container holding a set of specimens was removed from the furnace and its contents water quenched.

10. When each series was completed, the specimens were drawn at 500°F. for the purpose of causing the martensite to etch brown so that any massive iron carbide present could easily be distinguished by its whiteness. By microscopical examination of these specimens it was possible to determine the holding time necessary to complete first stage graphitization of all five compositions, both with and without pretreatment, for the particular heating rate and holding temperature employed.

11. The holding time necessary to complete first stage graphitization was arbitrarily chosen as the time required to produce a specimen in which, at a magnification of 100 diameters, no carbide particles could be found either in the central area or at the edge where the rim of carbide particles resembling a picture frame would be if it were present.

Results of First Stage Graphitization Tests

12. The results of the first stage graphitization tests are given in Table 2. Graphic representations of these data are shown in Figs. 2 and 3.

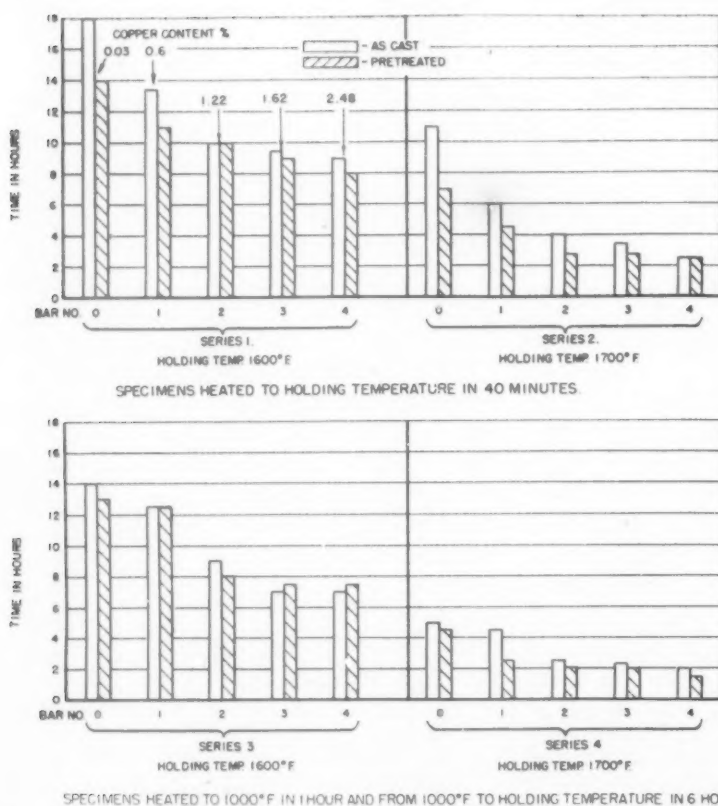


FIG. 2—TIME REQUIRED TO COMPLETE FIRST STAGE GRAPHITIZATION IN MALLEABLE CAST IRONS CONTAINING COPPER.

Table 2
HOLDING TIME IN HOURS REQUIRED TO COMPLETE FIRST STAGE GRAPHITIZATION

Bar No.	Copper, per cent	Series 1		Series 2		Series 3		Series 4	
		As-Cast	Pre-treated	As-Cast	Pre-treated	As-Cast	Pre-treated	As-Cast	Pre-treated
0	0.03	18	14	11	7	14	13	5	4½
1	0.60	13½	11	6	4½	12½	12½	4½	2½
2	1.22	10	10	4	2¾	9	8	2½	2
3	1.62	9½	9	3½	2¾	7	7½	2½	2
4	2.48	9	8	2½	2½	7	7½	2	1½

13. From these data it can be seen that additions of copper up to 1.22 per cent are much more effective than additions over 1.22

per cent in reducing the first stage holding time. Furthermore, the low temperature pretreatment reduces the first stage holding time for the irons below 1.22 per cent copper, but has very little effect on those with higher copper contents. The specimens rapidly heated to the first stage graphitizing temperature (series 1 and 2) showed a greater response to the effect of the low temperature pretreatment than did the specimens slowly heated to the holding temperature (series 3 and 4).

14. The effect of copper content, pretreatment, heating rate, and holding temperature on the graphite nodule size can be seen in Figs. 8 to 15, which also show the end points of the second stage graphitization tests. The photographs in these figures can be used for comparing the graphite nodule size of the specimens in series 1, 2, 3, and 4, which correspond to specimens in series 5, 6, 7, and 8,

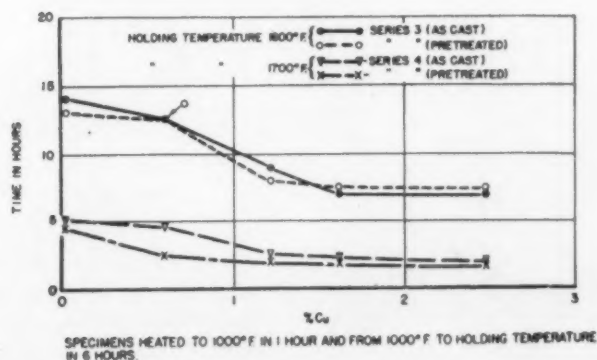
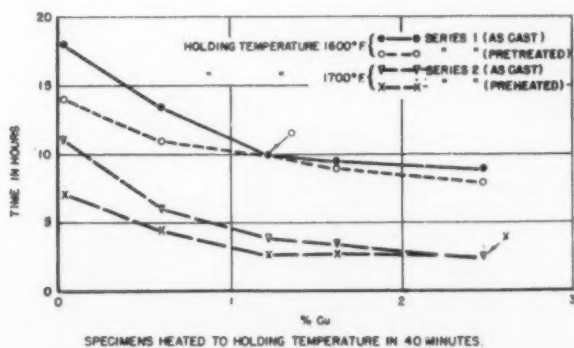


FIG. 3—TIME REQUIRED TO COMPLETE FIRST STAGE GRAPHITIZATION IN WHITE CAST IRONS CONTAINING COPPER.

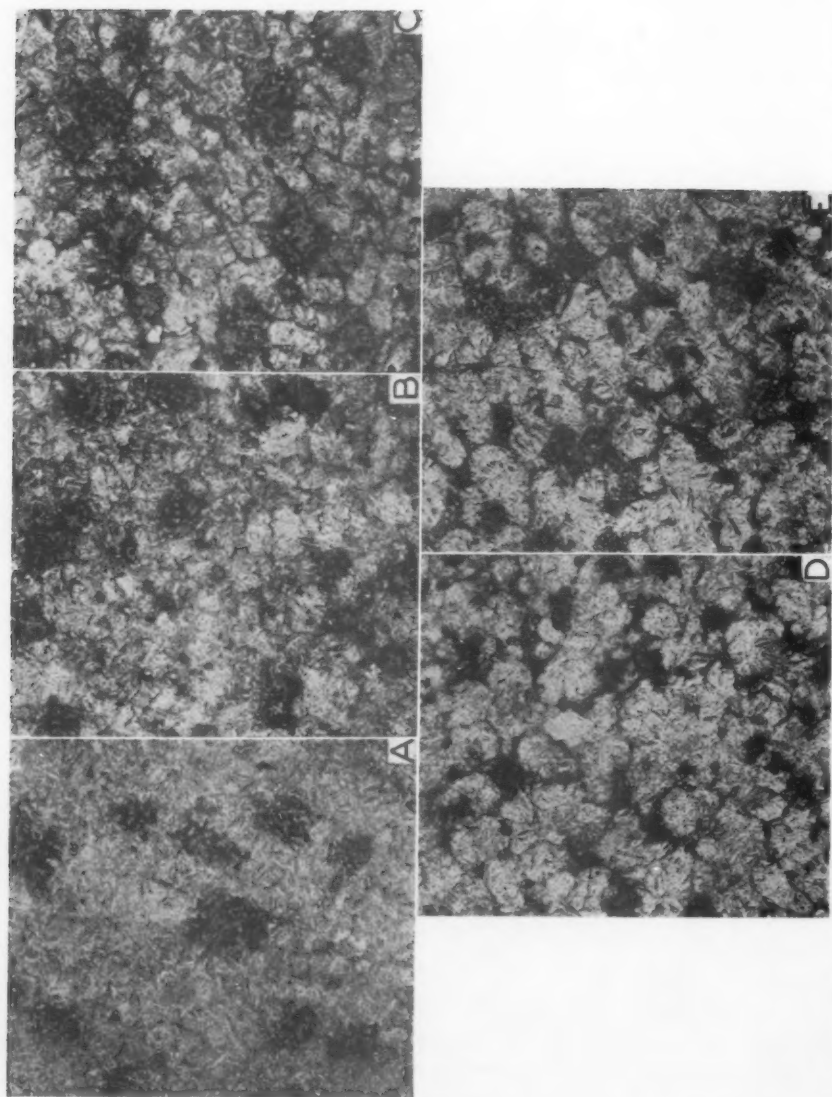


FIG. 4—MICROSTRUCTURES OF SPECIMENS WITHOUT PRETREATMENT FROM SERIES 3, WATER QUENCHED AFTER HOLDING AT 1600°F. LONG ENOUGH TO COMPLETE FIRST STAGE GRAPHITIZATION, SHOWING EFFECT OF COPPER CONTENT ON NETWORK STRUCTURE. A—BAR NO. 0—0.03 PER CNT COPPER, HELD 14 HRS. B—BAR NO. 1—0.60 PER CNT COPPER, HELD 12½ HRS. C—BAR NO. 2—1.22 PER CNT COPPER, HELD 9 HRS. D—BAR NO. 3—1.62 PER CNT COPPER, HELD 7 HRS. E—BAR NO. 4—2.45 PER CNT COPPER, HELD 7 HRS. ETCHED WITH NITAL. $\times 100$.

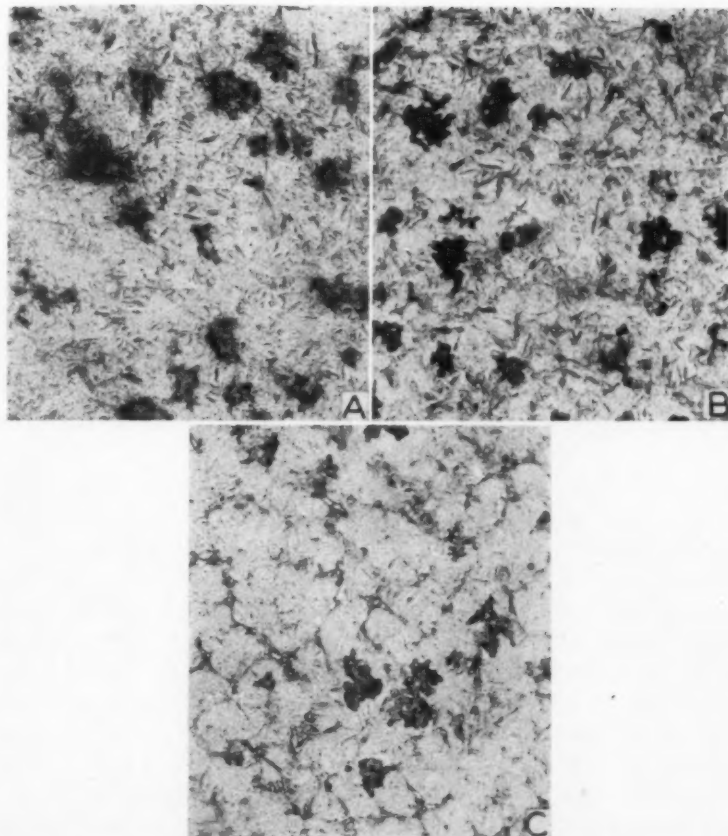


FIG. 5—MICROSTRUCTURE OF SPECIMENS WITHOUT PRETREATMENT, WITH 2.48 PER CENT COPPER, NEAR THE END OF FIRST STAGE GRAPHITIZATION CYCLES, SHOWING EFFECT OF HEATING RATE AND HOLDING TEMPERATURE ON NETWORK STRUCTURE. A—SPECIMEN HEATED TO 1700°F. IN 40 MINUTES, HELD 3 HOURS AND WATER QUENCHED. B—SPECIMEN HEATED TO 1000°F. IN 1 HOUR AND FROM 1000 TO 1700°F. IN 6 HOURS, HELD 2 HOURS AT 1700°F. AND WATER QUENCHED. C—SPECIMEN HEATED TO 1600°F. IN 40 MINUTES, HELD 9 HOURS AND WATER QUENCHED. ETCHED WITH NITAL. $\times 100$.

respectively, since the nodule size is determined in the early stages of the first stage graphitization.

15. The specimens from series 1, 2, and 3 that received the low temperature pretreatment still had a rim or "picture frame" of carbide particles after the central part had completely graphitized. This rim was not observed in the specimens of series 4 or in the specimens without pretreatment. The time for first stage graphitization of the pretreated specimens was dependent on the rate of

graphitization of the rim. The central part graphitized very rapidly and was often complete in less than half the time required to graphitize the rim.

16. In the course of the microscopical examination of the end point specimens of the first stage graphitization tests, a network of dark etching martensite, located in the areas occupied by the carbide network in the original structure, was observed in all of the specimens containing copper of series 1 and 3, and those specimens containing copper of series 4 that had been at the holding temperature 2 hours or less. It was found that this network did not exist in the specimens without copper but became more pronounced with successive increases in copper. Pretreatment did not affect the presence of this network. Figures 4 and 5 show the effect of copper content and holding temperature on the network.

Procedure Employed in Second Stage Graphitization Tests

17. The second stage graphitization tests consisted of determining the maximum cooling rate, from the first stage holding temperature, that would produce a fully ferritic specimen. These tests were conducted as follows: A container of specimens was placed in an electric resistance furnace and carried through one of the four first stage cycles described earlier in the paper. After holding at temperature long enough to insure complete graphitization of the massive carbides, the specimens were cooled at a constant rate to a temperature well below the critical point. Rates of cooling employed in the tests covered the range from 10 to 111°F. per hour. Control of the cooling rate was effected in the beginning of the investigation with a cam and clock mechanism which actuated the settings of a temperature controller. Later in the investigation, a temperature controller-reply system was employed which permitted obtaining any cooling rate above about 10°F. per hour.

18. The specimens were sectioned and polished for microscopical examination. The examination of these specimens for residual pearlite was confined to the central area so that the results would not be influenced by the presence of any pearlitic skin or "picture frame" that might be present. Examination was also made of the edges of the specimens to determine the extent of the pearlitic "picture frame," if present.

19. The malleableizing cycles of the four series, 5 to 8 inclusive, of second stage graphitization tests are shown graphically in Fig. 6. The heating time to holding temperature for series 5 and 6

was 30 minutes, while in the case of the series 7 and 8, the specimens were heated to 1000°F. in 1 hour and from 1000°F. to holding temperature in 6 hours.

Results of Second Stage Graphitization Tests

20. The maximum cooling rates that produced fully ferritic specimens in the four series of second stage graphitization tests are tabulated in Table 3 and shown graphically in Fig. 7. End points are not precise; instead they are cooling rates employed at which the specimens showed fully ferritic structures. The true end points

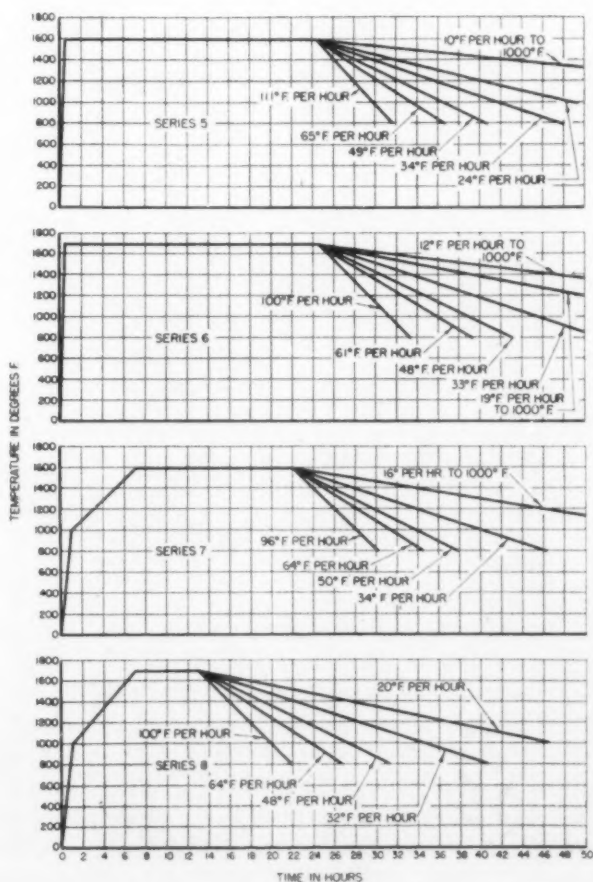


FIG. 6—MALLEABILIZING CYCLES EMPLOYED IN SECOND STAGE GRAPHITIZATION TESTS.

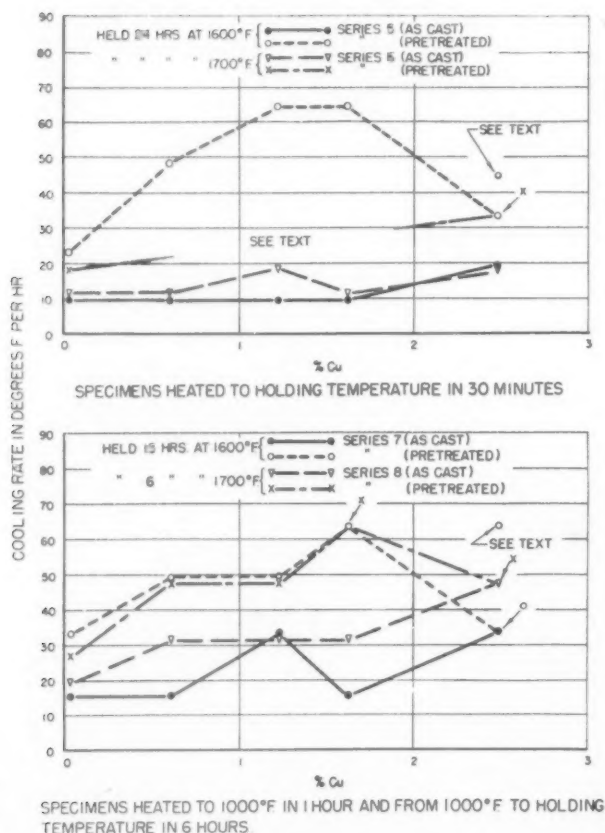


FIG. 7.—MAXIMUM COOLING RATE THAT WILL INSURE COMPLETE SECOND STAGE GRAPHITIZATION OF MALLEABLE CAST IRON CONTAINING COPPER.

lie between these cooling rates and the next higher rate of cooling employed in the series.

21. Photomicrographs of the specimens cooled at rates given in Table 3 are shown in Figs. 8 to 15. These micrographs show a representative field from the central area of each specimen.

22. From Fig. 7, it can be seen that for the malleableization cycles used, the most rapid second stage graphitization is obtained when the specimens containing between 1 and 2 per cent copper have been given the pretreatment of 8 hours at 600°F. Figures 8 to 15 show that the pretreated irons containing between 0.6 and 2 per cent copper have small, evenly distributed graphite nodules in a fine-grained ferrite matrix. Optimum refinement in nodule

size is obtained with copper content between 1 and 2 per cent. The nodules in the pretreated specimens with 2.48 per cent copper tend to be slightly coarser than in the specimens containing the lower percentages of copper. Copper decreases the nodule size of specimens which received no preliminary treatment.

Table 3

MAXIMUM COOLING RATE FROM FIRST STAGE HOLDING TEMPERATURE THAT PRODUCED FULLY FERRITIC SPECIMENS OF MALLEABLE IRON

Bar No.	Copper, per cent	Degrees Fahrenheit Per Hour							
		Series 5		Series 6		Series 7		Series 8	
		As-Cast	Pretreated	As-Cast	Pretreated	As-Cast	Pretreated	As-Cast	Pretreated
0	0.03	10	24	12	19	16	34	20	20
1	0.60	10	49	12	*	16	50	32	48
2	1.22	10	65	19	*	34	50	32	48
3	1.62	10	65	12	*	16	64	32	64
4	2.48	24	34	19	33	34	34	48	48

23. Additions of copper decrease the amount of pearlite in the picture frame (Figs. 16 [top] and 18 [bottom]), the effect being more pronounced with specimens after pretreatment.

24. The specimens of series 5 and 6 (rapidly heated to holding temperature) had a pearlitic core in addition to the picture frame (Fig. 16 [bottom]). This condition was observed in specimens low in copper with and without pretreatment. Increases in copper content, however, reduced the amount of pearlite in the core as well as in the picture frame.

25. Figures 8 to 15 show that the ferrite grains are refined but that they become progressively less uniform geometrically with increase in copper.

26. A ghost of the original carbide network was found to exist in the specimens containing copper of series 5 and 7 (Fig. 17 [top]). This ghost structure was observed as a white network in a dark brown matrix when the specimens were etched in picral. It was found that the last pearlite to graphitize in the central area of these specimens was the pearlite located in that area occupied by the original carbides (Fig. 17 [bottom]). The ghost structure did not exist in specimens held at 1700°F. during the first stage graphitization.

* The maximum cooling rates were not determined for these specimens.

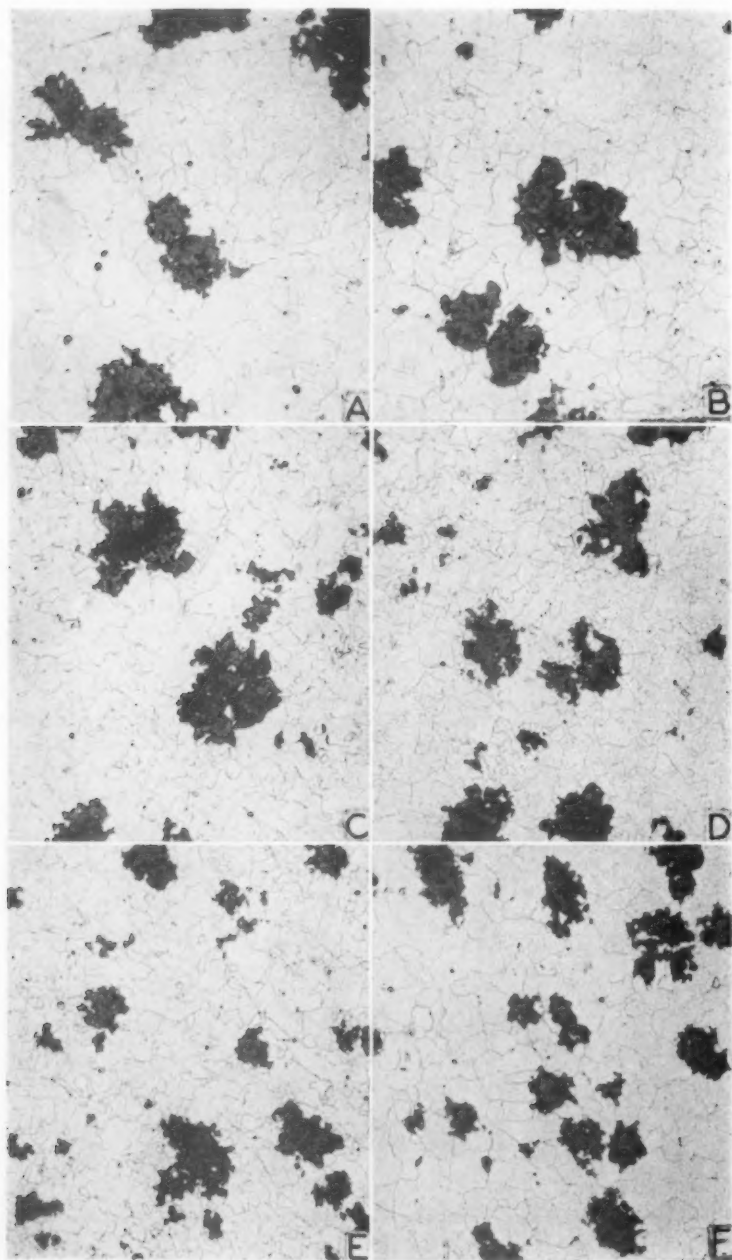


FIG. 8—SPECIMENS OF SERIES 5 HEATED TO 1600°F. IN 30 MINUTES, HELD 24 HOURS, AND COOLED AT INDICATED RATES. A—0.03 PER CENT COPPER; AS-CAST; COOLED 10°F. PER HOUR. B—0.60 PER CENT COPPER; AS-CAST; COOLED 10°F. PER HOUR. C—1.22 PER CENT COPPER; AS-CAST; COOLED 10°F. PER HOUR. D—1.62 PER CENT COPPER; AS-CAST; COOLED 10°F. PER HOUR. E—2.48 PER CENT COPPER; AS-CAST; COOLED 24°F. PER HOUR. F—0.03 PER CENT COPPER; PRETREATED; COOLED 24°F. PER HOUR. ETCHED WITH NITAL.

x100.

COMMENTS

27. It is general knowledge that the holding temperature is a potent factor affecting the time required to complete first stage graphitization. In the work described in the preceding paragraphs, it was shown that raising the holding temperature from 1600 to 1700°F. shortened the time for first stage graphitization of a commercial, copper-free, white iron by as much as one-half. A second factor of marked importance is the rate of heating to the holding temperature. As other investigators^{1, 4} have shown, heating white iron rapidly to the malleableizing temperature decreases the rate

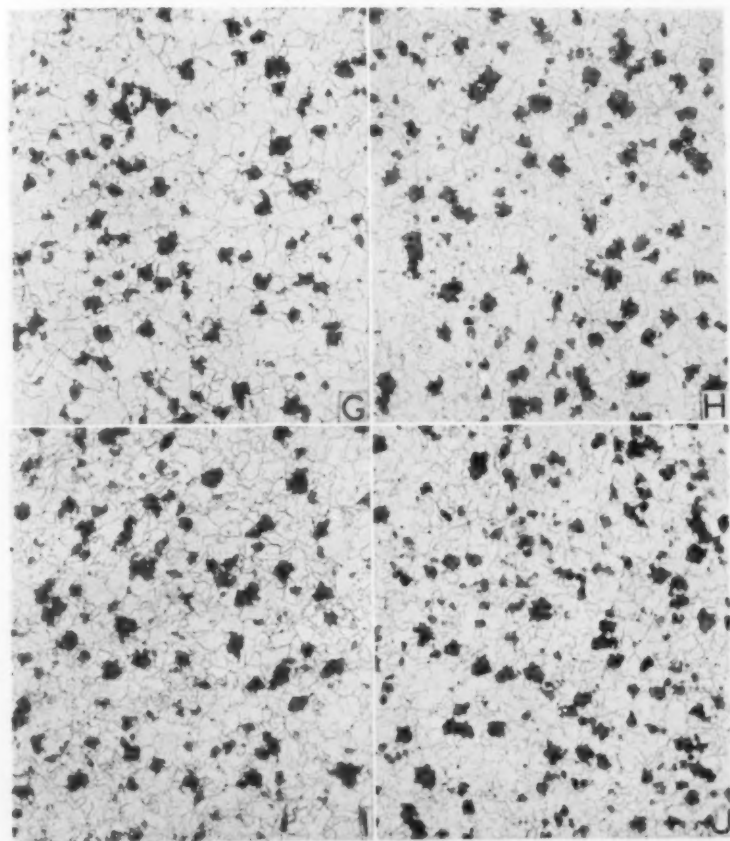


FIG. 9—CONTINUED FROM FIG. 8. G—0.60 PER CENT COPPER; PRETREATED; COOLED 49°F. PER HOUR. H—1.22 PER CENT COPPER; PRETREATED; COOLED 65°F. PER HOUR. I—1.62 PER CENT COPPER; PRETREATED; COOLED 65°F. PER HOUR. J—2.48 PER CENT COPPER; PRETREATED; COOLED 34°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

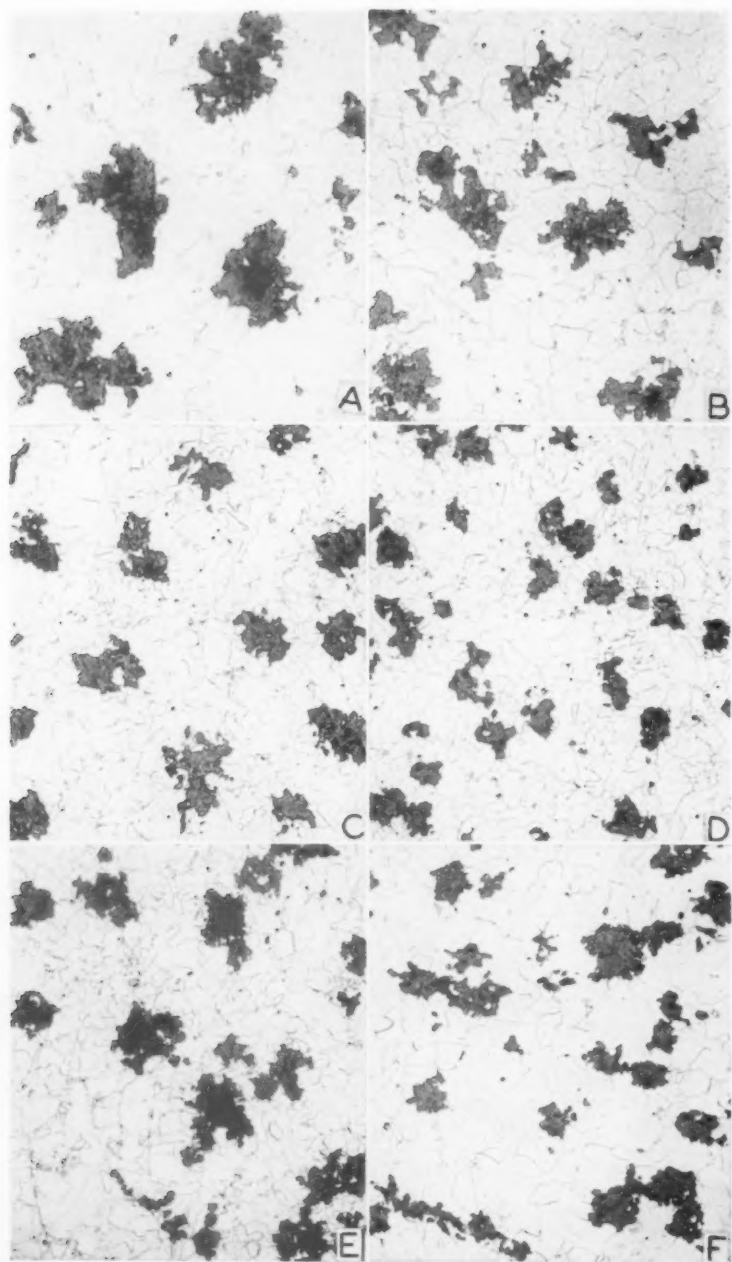


FIG. 10—SPECIMENS OF SERIES 6 HEATED TO 1700°F. IN 30 MINUTES, HELD 24 HOURS, AND COOLED AT INDICATED RATE. A—0.03 PER CENT COPPER; AS-CAST; COOLED 12°F. PER HOUR. B—0.60 PER CENT COPPER; AS-CAST; COOLED 12°F. PER HOUR. C—1.22 PER CENT COPPER; AS-CAST; COOLED 19°F. PER HOUR. D—1.62 PER CENT COPPER; AS-CAST; COOLED 12°F. PER HOUR. E—2.49 PER CENT COPPER; AS-CAST; COOLED 19°F. PER HOUR. F—0.03 PER CENT COPPER; PRETREATED; COOLED 19°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

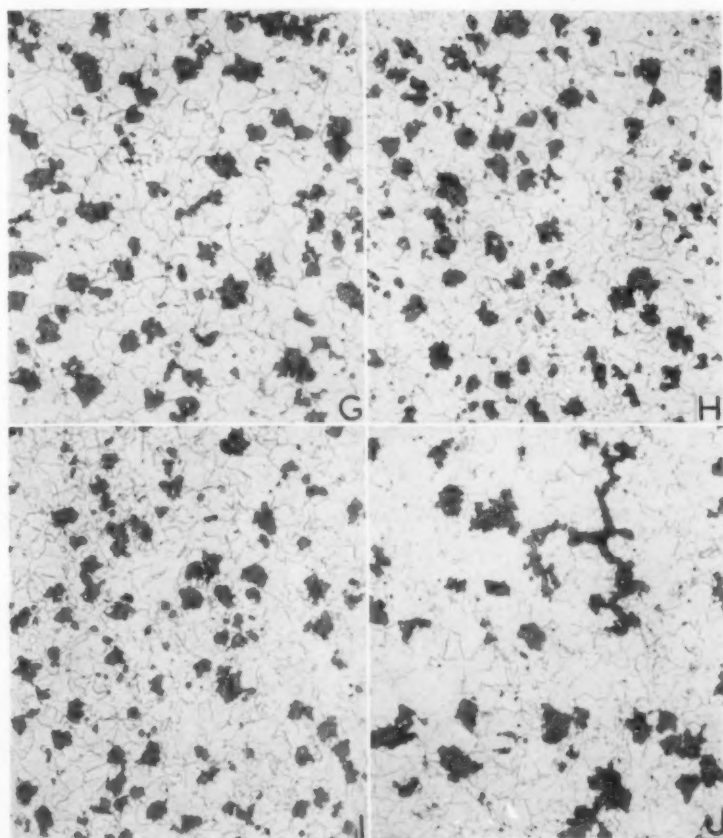


FIG. 11—CONTINUED FROM FIG. 10. G—0.60 PER CENT COPPER; PRETREATED; COOLED 48°F. PER HOUR*. H—1.22 PER CENT COPPER; PRETREATED; COOLED 48°F. PER HOUR*. I—1.62 PER CENT COPPER; PRETREATED; COOLED 48°F. PER HOUR*. J—2.48 PER CENT COPPER; PRETREATED; COOLED 33°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

at which the iron malleableizes. Again using the copper-free iron to illustrate, it is observed that the holding time is considerably less for specimens heated to 1000°F. in 1 hour and from 1000°F. to 1600 or 1700°F., as the case might be, in 6 hours (series 3 and 4) than for specimens heated rapidly to 1600 or 1700°F. (series 1 and 2). Heating the specimens more slowly to the malleableizing temperature also favors the formation of smaller, more closely-spaced temper carbon nodules, as Figs. 8 to 15 inclusive show.

* The maximum cooling rate was not determined for these specimens.

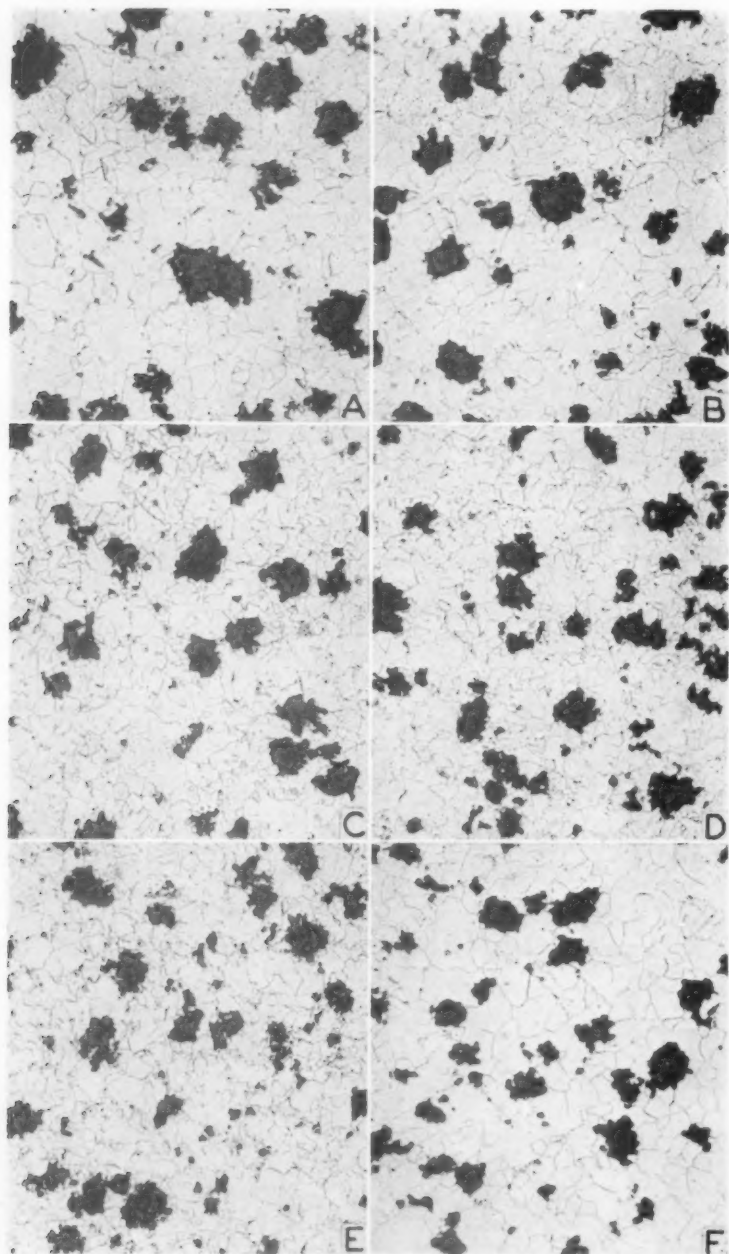


FIG. 12—SPECIMENS OF SERIES 7 HEATED TO 1000°F. IN 1 HOUR AND FROM 1000 TO 1600°F. IN 6 HOURS, HELD 15 HOURS, AND COOLED AT INDICATED RATE. A—0.03 PER CENT COPPER; AS-CAST; COOLED 16°F. PER HOUR. B—0.60 PER CENT COPPER; AS-CAST; COOLED 16°F. PER HOUR. C—1.22 PER CENT COPPER; AS-CAST; COOLED 34°F. PER HOUR. D—1.62 PER CENT COPPER; AS-CAST; COOLED 16°F. PER HOUR. E—2.48 PER CENT COPPER; AS-CAST; COOLED 34°F. PER HOUR. F—0.03 PER CENT COPPER; PRETREATED; COOLED 34°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

28. Moderate effects of holding temperature during first stage graphitization and rate of heating to the holding temperature were also observed on the rate of the second stage graphitization. As a rule, second stage graphitization was accelerated both by the higher holding temperature and by the slower rate of heating to the holding temperature. The slower rate of heating to the holding temperature was particularly effective in increasing the rate of graphitization during the second stage.

29. The investigations clearly indicate that two other factors, the copper content, and the preliminary heating of the iron for

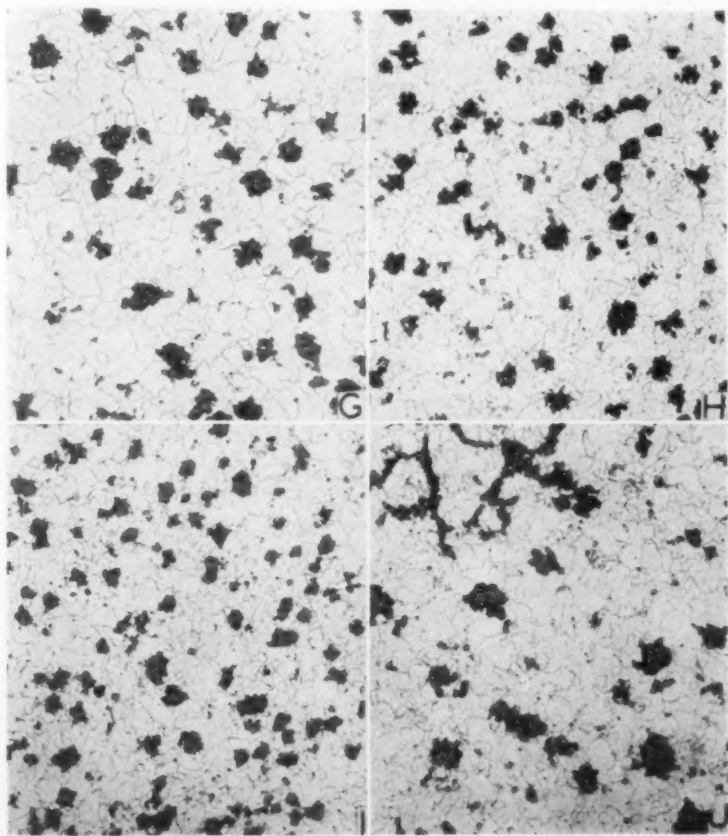


FIG. 13—CONTINUED FROM FIG. 12. G—0.60 PER CENT COPPER; PRETREATED; COOLED 50°F. PER HOUR. H—1.22 PER CENT COPPER; PRETREATED; COOLED 50°F. PER HOUR. I—1.62 PER CENT COPPER; PRETREATED; COOLED 64°F. PER HOUR. J—2.48 PER CENT COPPER; PRETREATED; COOLED 34°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

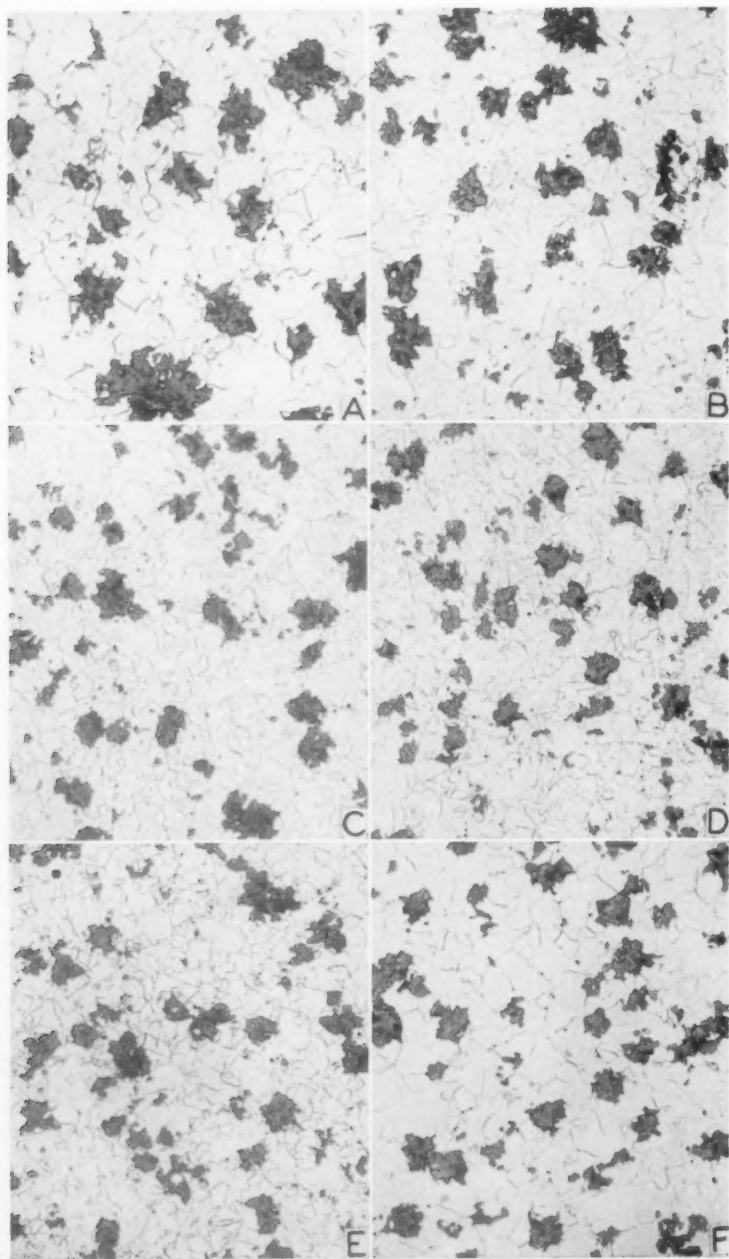


FIG. 14—SPECIMENS OF SERIES 8 HEATED TO 1000°F. IN 1 HOUR AND FROM 1000 TO 1700°F. IN 6 HOURS, HELD 6 HOURS, AND COOLED AT THE INDICATED RATE. A—0.03 PER CENT COPPER; AS-CAST; COOLED 20°F. PER HOUR. B—0.60 PER CENT COPPER; AS-CAST; COOLED 32°F. PER HOUR. C—1.22 PER CENT COPPER; AS-CAST; COOLED 32°F. PER HOUR. D—1.62 PER CENT COPPER; AS-CAST; COOLED 32°F. PER HOUR. E—2.48 PER CENT COPPER; AS-CAST; COOLED 48°F. PER HOUR. F—0.03 PER CENT COPPER; PRETREATED; COOLED 20°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

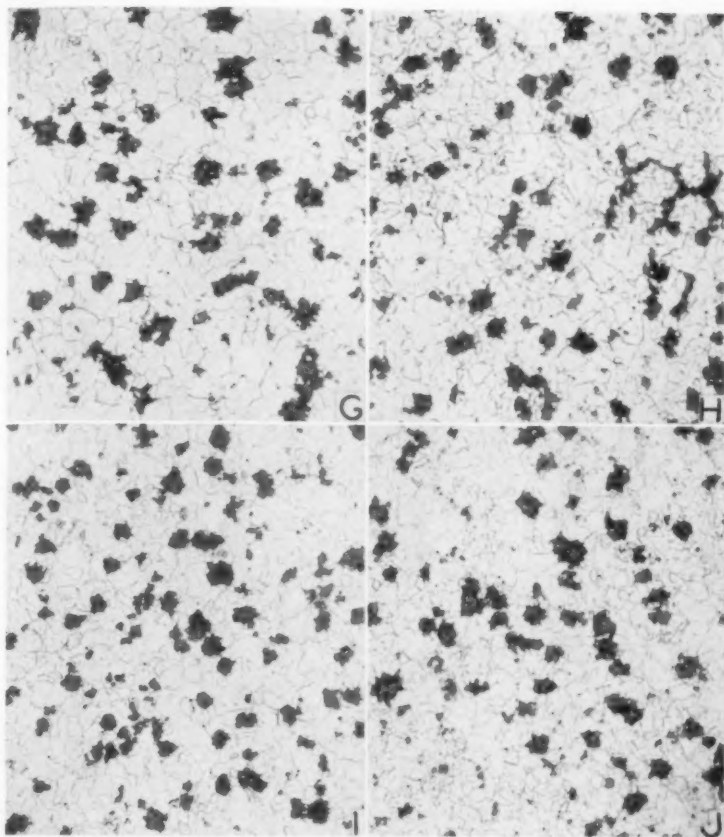


FIG. 15—CONTINUED FROM FIG. 14. G—0.60 PER CENT COPPER; PRETREATED; COOLED 48°F. PER HOUR. H—1.22 PER CENT COPPER; PRETREATED; COOLED 48°F. PER HOUR. I—1.62 PER CENT COPPER; PRETREATED; COOLED 64°F. PER HOUR. J—2.48 PER CENT COPPER; PRETREATED; COOLED 48°F. PER HOUR. ETCHED WITH NITAL. $\times 100$.

an extended time at 600°F., operate to affect the graphitizing of commercially produced white iron in both the first and second stages. Figures 8 to 15, inclusive, show that either copper in the iron or the pretreatment of the iron at 600°F. causes a moderate reduction in graphite nodule size. Both factors accelerate graphitization in the first and second stages, the pretreatment being especially effective during the second stage of graphitization. When the specimens with copper contents between 0.6 and 1.62 per cent are subjected to pretreatment, the nodule size is drastically reduced. In this case, variations in the heating rate and holding temperature

have little or no effect on the nodule size. The drastic reduction in nodule size is accompanied by a marked increase in graphitizing rate in both stages. This is very well illustrated in Tables 2 and 3.

30. Figures 8 to 15, inclusive, and Tables 2 and 3 likewise indicate that the nodule size has comparatively little effect on the time for first stage graphitization, but that the reduced nodule size

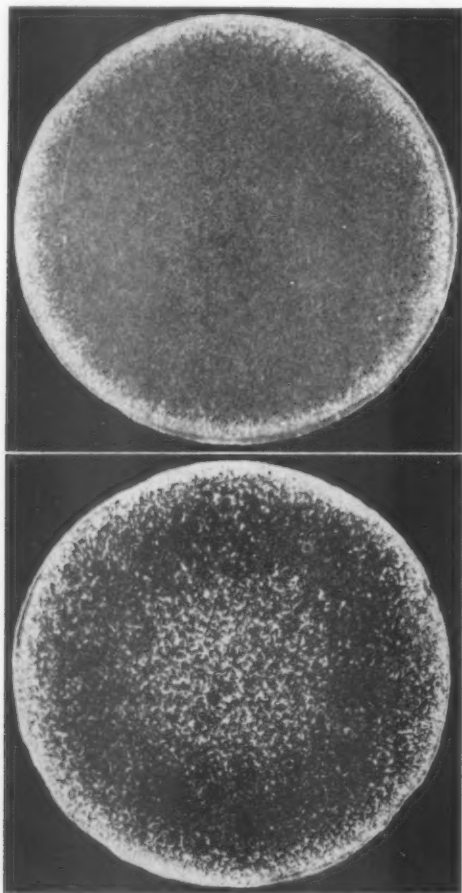


FIG. 16—(TOP) SPECIMEN SHOWING A TYPICAL CASE OF PEARLITIC PICTURE FRAME. THE WHITE AREAS ARE PEARLITE AND THE DARK AREAS FERRITE. (BOTTOM) SPECIMEN SHOWING A PEARLITIC PICTURE FRAME AND A PEARLITIC CORE. THE WHITE AREAS ARE PEARLITE AND THE DARK AREAS FERRITE. THIS CONDITION WAS FOUND TO EXIST IN THE SPECIMENS OF SERIES 5 AND 6 (RAPIDLY HEATED TO HOLDING TEMPERATURE) THAT WERE LOW IN COPPER; HOWEVER, INCREASES IN COPPER REDUCED THE AMOUNT OF PEARLITE IN BOTH THE CORE AND PICTURE FRAME. ETCHED WITH NITAL. $\times 3$.

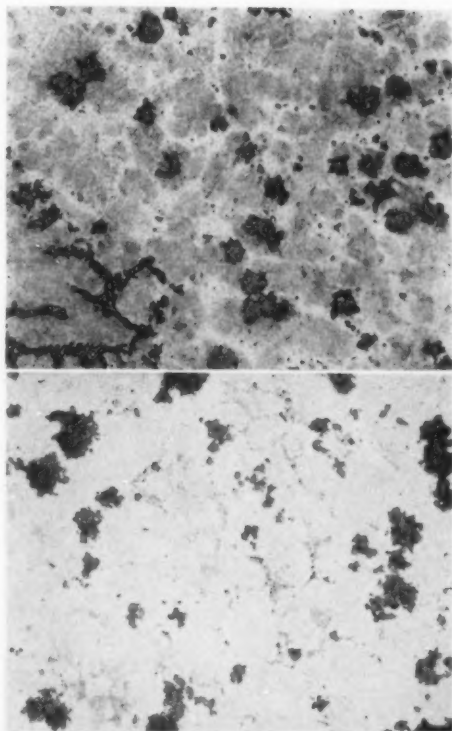


FIG. 17—(TOP) SPECIMEN CONTAINING 2.48 PER CENT COPPER; AFTER COMPLETE MALLEABLEIZATIONS IN SERIES 7. THE GHOST OF THE ORIGINAL CARBIDE NETWORK IS PRESENT IN THIS FULLY MALLEABLEIZED SPECIMEN. (BOTTOM) SPECIMEN CONTAINING 1.62 PER CENT COPPER; AFTER PARTIAL MALLEABLEIZATION IN SERIES 7. THE PEARLITE IN AREAS OCCUPIED BY THE ORIGINAL CARBIDE NETWORK IS THE LAST TO GRAPHITIZE. ETCHED WITH PICRAL. $\times 100$.

resulting from pretreatment or from copper or from both is very effective in accelerating second stage graphitization.

31. These observations may be explained, perhaps, by the fact that the nodules form in or alongside of the massive carbide particles; hence, there is very little distance, relatively speaking, for the carbon to diffuse through the matrix in the first stage of malleableization, but in the second stage the carbon must diffuse not only from areas formerly occupied by the carbide but also from areas that were the ground mass in the original structure. In the latter case, the increased number of nodules would shorten the distance the carbon must diffuse. The decomposition rate of massive carbide is another factor that may tend to control the graphitizing rate during the first stage. It may or may not be the deter-

mining factor, depending on the stability of the carbide.

32. The resultant effect of pretreatment of the iron without copper is equivalent to an addition of about 0.5 per cent copper in iron without pretreatment, in reducing first stage holding time. This can be seen from Fig. 3.

33. The graphite nodules, Fig. 4, C, D and E inclusive, are located in the network which apparently outlines the areas occupied

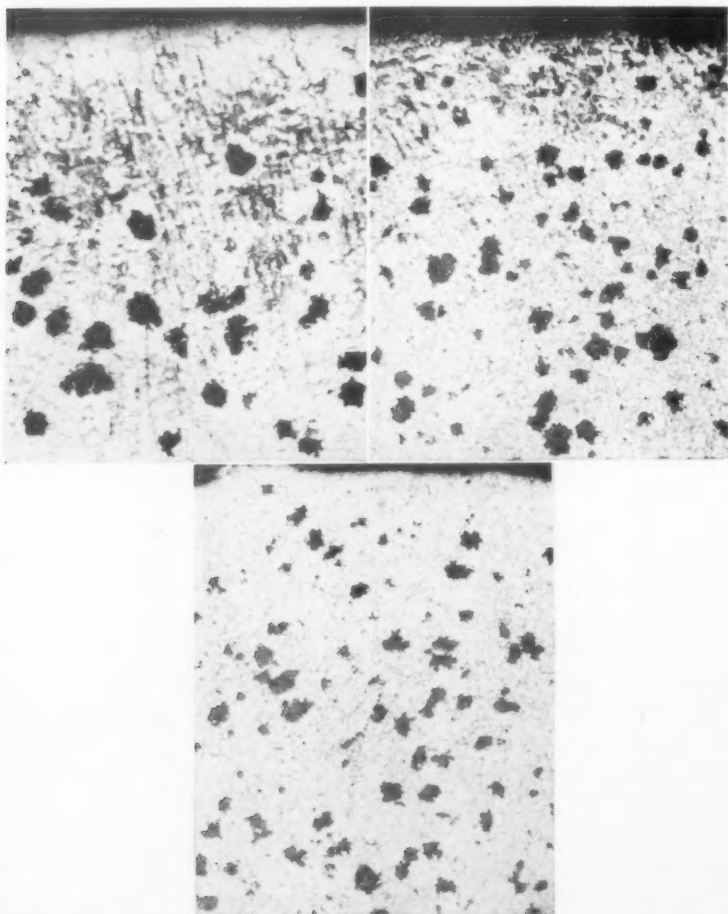


FIG. 18—PHOTOMICROGRAPHS SHOWING THE EFFECT OF COPPER ON THE PEARLITE PICTURE FRAME. ALL THREE SPECIMENS WERE GIVEN THE SAME TREATMENT WITH VARYING COPPER CONTENTS. (TOP LEFT) SPECIMEN CONTAINING 0.03 PER CENT COPPER. (TOP RIGHT) SPECIMEN CONTAINING 1.22 PER CENT COPPER. (BOTTOM) SPECIMEN CONTAINING 2.48 PER CENT COPPER. ETCHED WITH NITAL. $\times 50$.

by the massive iron carbide in the original structure. This network, seemingly, is the result of copper segregation since it becomes more pronounced with increasing copper. The fact that the network was not found in the specimens held at the higher temperature, 1700°F. , also indicates copper segregation since at the higher temperature the copper would have had a better opportunity to diffuse.

34. In this study it was found that pretreatment increases the tendency toward a rim of carbide particles during first stage graphitization, but has little effect on the pearlitic picture frame found at the completion of second stage graphitization provided all the massive carbide has previously been decomposed. On the other hand, copper is not effective in removing the rim of carbide particles found to be present at the end of first stage graphitization, but is powerful in reducing the amount of pearlite in the picture frame found at the completion of second stage graphitization. Furthermore, as shown in Fig. 18, copper, apparently, reduces drastically the amount of decarburization occurring during the malleableizing cycle.

35. The results of the graphitizing time studies were condensed in Table 4, into what might be termed "idealized malleableizing cycles." These cycles were determined by adding together (1) the time for pretreatment, in this case either 0 or 8 hours, (2) the time of heating from the pretreating temperature (600°F.) to the temperature of graphitizing in the first stage when the specimens were pretreated, or from room temperature when they were not pretreated, (3) the minimum time to effect complete decomposition of massive carbide during the first stage, and (4) the time to cool from the first stage graphitizing temperature to 1100°F. at the maximum rate that would cause complete graphitization during the second stage. They represent the minimum time to complete graphitization of the irons when the steps involved in the process vary in accordance with the factors discussed throughout this paper. Total times are given to the nearest hour.

36. The time for pretreatment of 8 hours is considerably longer than is necessary¹²; hence, the time cycles given in the table for pretreated specimens could be reduced as much as 4 to 6 hours without, seemingly, affecting the malleableizing results. Taking that into account, the comparison of the malleableizing times for the irons with and without pretreatment becomes even more striking. It is conceivable, then, to cut in half the malleableizing cycle

Table 4
MINIMUM MALLEABLEIZING CYCLES FOR VARIOUS COMBINATIONS OF FACTORS
Time in Hours Required for Complete Malleableization

Copper, per cent	Cycle Involving Rapid Heating to 1600° F. Pretreatment		Cycle Involving Rapid Heating to 1700° F. Pretreatment		Cycle Involving Slow Heating to 1600° F. Pretreatment		Cycle Involving Slow Heating to 1700° F. Pretreatment	
	None	8 Hrs. 600° F.	None	8 Hrs. 600° F.	None	8 Hrs. 600° F.	None	8 Hrs. 600° F.
0.03	67	43	62	47	52	35	42	50
0.60	64	30	57	*	51	38	30	30
1.22	61	26	36	*	31	33	28	30
1.62	60	25	—	*	45	31	28	27
2.48	31	31	35	29	29	37	22	29

* Complete information on second stage graphitization for these specimens not obtained.

for some commercial white irons by using about 1 per cent copper and by employing a preliminary treatment at around 600°F.

SUMMARY

37. From this study the following conclusions may be drawn :

1. A white cast iron of the base composition used in this study will respond more rapidly to first and second stages of graphitization, if it is held at a higher temperature during first stage graphitization, if it is heated more slowly to the holding temperature, if it contains copper, and if it is subjected to a preliminary treatment at around 600°F. for 8 hours.
2. The effects of copper on accelerating first and second stage graphitization are intensified sharply by the preliminary treatment.
3. The combined effect of copper and preliminary treatment is to reduce, drastically, the temper carbon nodule size.
4. The size of the temper carbon nodules formed on annealing white iron containing 0.6 to 2 per cent copper after a preliminary low temperature treatment are not affected by the holding temperature or by the rate of heating to the first stage graphitizing temperature.
5. Pretreatment increases the tendency for a rim of carbide particles to persist during first stage graphitization, but has little effect on the pearlitic picture frame found at the completion of second stage graphitization, provided all the massive carbide has previously been decomposed.
6. Copper is not effective in removing the rim of carbide particles found during first stage graphitization, but is powerful in reducing the amount of pearlite in the picture frame sometimes found at completion of second stage graphitization. Copper also reduces decarburization occurring during the malleableizing cycle.
7. A network pattern which apparently outlines areas occupied by the massive iron carbide in the original structure appears in the copper containing irons malleableized at 1600°F. This network does not exist in irons malleableized longer than 2 hours at 1700°F. indicating that the network is the result of dendritic segregation of copper (on a micro scale). The areas occupied by the network are last to graphitize during the second stage.

ACKNOWLEDGEMENT

38. The investigation described in the paper constituted one phase of a research program sponsored at Battelle Memorial Institute by Anaconda Copper Mining Co., Phelps-Dodge Corp., and Kennecott Copper Corp. for the benefit of the copper industry.

39. The writers express their appreciation to the sponsors of the research investigation for permission to publish this work. They also thank Yale & Towne Mfg. Co. for supplying the white cast iron specimens used in the investigation.

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DISCUSSION

Presiding: C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

J. H. LANSING¹: I wonder if Dr. Lorig has some figures on the physical and mechanical properties after the addition of the various amounts of copper?

DR. LORIG: Our physical and mechanical properties did not show up well because the reduced sections of the bars were somewhat porous. We did not want to report them. It did not seem to make much difference whether there were fine or coarse nodules, the ductility was about the same. I would not want to say that this is an exact analysis of the effect. We will find that out later, if we do any further work.

D. P. FORBES²: We make quite a few malleable castings using copper. We noted one very definite improvement in metal which had gone through the normal malleableizing cycle (which is rather extended), namely, the impact properties (not the Izod test but actual impact on specific castings) were very greatly improved with the addition of copper. The bars, as a rule, had a tensile strength of around 60,000 lb. per sq. in. and a yield strength around 43,000 lb. per sq. in. I am talking now of an addition of about 0.75 per cent copper. The elongation averaged a little higher but not much more than would be expected without the copper addition. That was with an analysis which would range around 2.50 per cent carbon with 1.00 per cent silicon. The metal was completely malleableized. It was not pearlitic material.

DR. LORIG: Those figures are very interesting. The effect of copper on the mechanical properties is very noticeable, but any effect of the nodule size on the mechanical properties was not apparent.

MEMBER: What was the effect of the copper on primary graphitization in larger sections?

DR. LORIG: We noticed some primary graphite in the grip ends of the 1.6 per cent and 2.48 per cent copper irons. The other bars were completely white.

F. L. HARRIS³: Has the author found any change in the lower critical point in his experiments with copper?

DR. LORIG: Not very much.

MR. HARRIS: We found that our lower critical point went up slightly.

DR. LORIG: It may be possible for it to go up. We did not examine it very closely, but Smith and Palmer, who worked on copper malleable iron 8 or 9 years ago, indicated that an addition of 1.33 per cent copper lowered the critical point about 18°F. for an iron with a composition similar to that used in this study.

CHAIRMAN JOSEPH: On some work which we did on copper a number of years ago, we found that the ultimate strength and the yield strength were increased probably from 4 to 8 per cent, but the elongation dropped

¹ Malleable Founders' Society, Cleveland, Ohio.

² Gunite Foundries Corp., Rockford, Ill.

³ Belle City Malleable Iron Co., Racine, Wis.

off from 1 to 2 per cent. Where we had a normal iron the elongation would drop from 15 per cent to around 12 per cent. I have talked to a number of other people about it, and they find that is usually true.

MEMBER: We added 1 to 1½ per cent copper to our air-furnace malleable and found the same thing, namely, that we gained 2000 or 3000 lb. per sq. in. tensile strength with 1 or 2 per cent decrease in elongation.

CHAIRMAN JOSEPH: We also found that 100 points of copper were equal to 10 points of silicon in promoting primary graphitization. This work was all done on 2.60 to 2.80 per cent carbon iron.

W. D. McMILLAN⁴: As I recall, 1 per cent copper is just about as effective from the standpoint of annealing as 0.5 per cent silicon and is equivalent to about 0.1 per cent silicon from the standpoint of inducing primary graphite.

CHAIRMAN JOSEPH: That is about right. Is there any practical way this preheating can be done, making it pay from the standpoint of cost?

DR. LORIG: I do not think it should be difficult to heat a casting between 300°F. and 700°F. It would be particularly adapted to a practice where there is continuous malleableizing without packing material. It is particularly effective when the carbon content is low. As in the quick anneal type of malleable iron, I can see the possibility of reducing the malleableizing time by as much as four or five times and successfully completing the malleableization of some of the quick malleable irons in an hour or so, whereas, otherwise, it might take 10, 12 or even 20 hours. It should not be difficult to heat a casting to a low temperature and hold it there. It does not have to be done at any particular temperature, and I think the temperature could be varied a great deal. It would be interesting to know why pretreatment works, but I think that is still one of those questions that will have to be answered by further research work.

CHAIRMAN JOSEPH: Do you think more tonnage could be obtained in the same length of time through a kiln or oven 120 ft. long if it was preheated at 600°F. for 3 hours and then raised up to 1750°F.?

DR. LORIG: I believe it could.

MR. LANSING: From the standpoint of the regular pot type anneal, this preheating is really a rather academic question, since it takes place as a necessary part of the process in attaining temperature.

CHAIRMAN JOSEPH: I wonder how much could be saved in the new type atmosphere control ovens, because, in our atmosphere control, we heat the material as fast as we can, and still we cannot bring it up too fast. It takes just so long to bring it up to temperature. We cannot reach a temperature of 1300°F. in the radiant tube type of atmosphere control oven in less time than 4 hours. Then, from 1300°F. to 1500°F., it takes another 2 hours, and the heating rate has to be watched in the range from 1550°F. to 1750°F. In this range, we do go up a little slower than we could go.

M. E. McKINNEY⁵: This question seems to be rather indefinite. We say from 300° to 600°F. in so many hours. Does it make any difference whether it is at 300°F. all the time or at 600°F.?

⁴ McCormick Works, International Harvester Co., Chicago, Ill.

⁵ International Harvester Co., Hamilton, Ont., Canada.

DR. LORIG: No. It is a little more effective at 600°F.

MR. MCKINNEY: What is the total time?

DR. LORIG: Three hours.

MR. MCKINNEY: Two hours at 600°F.?

DR. LORIG: Yes.

MEMBER: In the same graphitization, does this compare with Boegehold's work*?

DR. LORIG: Boegehold shows that it takes a longer time to anneal this iron if it is heated very rapidly than if it is heated slowly. The time necessary to heat it up to the holding temperature, plus the time at temperature, may be shorter than if heated rapidly to that temperature and held.

CHAIRMAN JOSEPH: In heavy castings, as you pointed out, the temper carbon spots are much smaller when copper is used. We found that out and on some heavy castings where the temper carbon spots must be small, we add copper. If the carbon spots are large, they will show up very prominently when the job is machined and polished. The copper does make them smaller.

MEMBER: Would there be any difference in the time to get the temperature up to 900°, 1000° or 1100°F.?

DR. LORIG: Not very much.

MEMBER: Would it have any adverse effect?

DR. LORIG: No, it is most pronounced at around 600° to 700°F. If that range of temperature is exceeded, it is not quite as pronounced in effect, but it still shows up.

MEMBER: Does it make any difference when cooling from 800°F. down?

DR. LORIG: That does not seem to make any difference. That temperature can either be held, brought up to the annealing temperature or brought down to room temperature.

CHAIRMAN JOSEPH: This reduced time of malleablizing by preheating was definitely shown to be more prominent on some castings than others. The castings on which it was shown to be the most prominent were made from different raw materials. Certain irons can be preheated without a decrease in time, while a casting made from other raw materials will cut the time down very greatly, so the question of raw materials enters into the problem very much.

DR. LORIG: The Chairman hit on one factor when he intimated that the hydrogen content has something to do with it.

MR. HARRIS: In Table 4 on the samples heated to 1600°F., with copper added, and preheated, the time was cut down, but on the samples heated to 1700°F., cast and preheated, the total time difference between the as cast and the preheated castings was negligible.

DR. LORIG: That is right. The holding temperature has something to do with the rate of graphitization. At 1600°F., the total time was 67 hours; at 1700°F., it was 62 hours. With slower heating, it was 52 hours at 1600°F., and 42 hours at 1700°F.

*Boegehold, A. L., "Factors Influencing Annealing Malleable Iron," *TRANSACTIONS, A.F.A.*, vol. 46, pp. 449-490 (1938).

MR. HARRIS: In Table 4, under the column, were the last 1700°F. as cast castings completed in less time than the preheated castings?

DR. LORIG: Yes. We used 8 hours as a pretreating time. That is a long time and, in some cases, more than enough. Had we reduced it to 2 hours, our balance would have been a little bit better in favor of pretreatment.

MR. McMILLAN: While a relatively slow rate of heating from 1500° to 1700°F. is effective in controlling graphite size in a high carbon cupola iron, we do not attempt to slow down the rate of heating an iron of the high silicon, low carbon type (1.60 per cent silicon-2.20 per cent carbon). We heat up a charge of 1200 lb. in 2½ hours. I believe the higher carbon has much to do with the larger graphite nodules. It may be that the method of melting or handling the molten metal (such as the addition of steel) may tend to produce fewer nuclei than the conventional air furnace practice using pulverized coal. In the iron we run, there are about 50 nodules in a field at 100 magnification. We call this the count. We have not attempted to convert the count to a figure such as the number per sq. mm. or sq. in. I would like to ask if this was all air furnace iron?

DR. LORIG: Yes.

MR. McMILLAN: And coal-fired?

DR. LORIG: I am not sure.

MR. McMILLAN: Iron normally melted by a good accepted practice responds to the preheat treatment. However, there are some things which may occur in the melting which will inhibit the increase in nuclei count brought about in preheating. If the metal is oxidized to a marked degree and a major addition of silicon is made, the graphite size and count is "set." Perhaps this oxidation and heavy silicon addition has the effect of "killing" the heat. When the iron is properly melted, the preheat treatment may bring about a count as high as 500 at 100x. This condition, an increase in the number of graphite nodules, has been known to operate on straight cupola iron, cupola air furnace duplex, coal-fired and oil-fired air furnace iron, providing the amount of oxidation has not been excessive.

MESSRS. LORIG and ELSEA: Since the paper was not preprinted, written discussions were not submitted. However, the authors wish to express their sincere appreciation to those who contributed to the oral discussion of the paper.

Cast Iron Strength vs. Structure

BY ROBERT R. ADAMS*, COLUMBUS, OHIO

Abstract

In this paper the author undertakes a difficult piece of work, namely, to correlate the strength of cast iron with its structure. The forepart of the paper lays the groundwork for his investigations by reporting the results of previous investigations and in a general manner, discusses graphite formation mechanisms. In order to correlate the physical properties with the structure of cast iron, he points out that the following structural characteristics must be considered: (1) cell size, (2) graphite characteristics and (3) matrix structure. He then proceeds with the comparison on the basis of tensile and transverse strengths with the structure of 176 specimens. From his investigation, he concludes that tensile strengths correlate very well with structures, but that the same is not entirely true in the case of transverse strength. Brinell hardness does not correlate well with structure. Graphite size exerts an important influence on the strength properties of cast iron, as does cell structure. He does not draw quantitative conclusions, but by means of charts, shows the general relationship existing between strength and structure in the irons studied.

1. Even a novice can look at a microsection of cast iron and tell whether it is of the high strength or of the soft, open type. With a considerable background of experience, an expert can look at the microstructure or at the characteristics of the fracture and make a pretty good guess at the actual strength. He realizes that there is some sort of correlation between the strength of the iron and the size and distribution of its graphite flakes. This correlation is enough in evidence that numerous investigators, from the time of

* Research Engineer, Battelle Memorial Institute.

NOTE: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

Howe on, have considered the feasibility of developing some quantitative relationship.

2. The commercial need for this correlation does not, at first thought, appear very great. Cast iron is not such a high priced material that a few pounds cannot be spared for an arbitration bar, and transverse testing of the bar is not costly; so a direct strength measurement can be obtained at little expense. However, such a measurement tells only what the properties of that lot of metal are when cast as the arbitration bar. It does not tell the strength of iron poured into large sections. Large diameter test bars are probably more indicative of these conditions, but their testing may not be feasible with the equipment at hand. Occasionally, but altogether too infrequently, pilot castings are subjected to complete destructive tests and the properties correlated with standard test bars. As the use of inoculated irons becomes more prevalent, the difficulties of obtaining accurate correlations become more pronounced.

3. The only completely accurate method of determining the strength of a certain section of a casting is to test a specimen cut from that section. If this were to be done by the usual methods of physical testing, it would mean destruction of the usefulness of the casting. On the other hand, it is generally possible to arrange for trepanning a small specimen from the heavy section without injury to the casting. In such a case, the engineer may be decidedly interested in having an estimate of the uniformity of properties across the section. He might also well prefer that this estimate be in terms of strength, which he can understand, rather than in terms of structure, which he may not understand. Hence, efforts to bring out some quantitative relation between structure and strength have a practical, as well as an academic, justification.

Previous Investigations and Results

4. Notable efforts toward the development of a quantitative relation between strength and structure have been made by Corson¹, Portevin², and Mahin and Hamilton³. Corson developed a mathematical formula for the calculation of the strength. This method requires the determination of both total and graphitic carbon, and quantitative measurements of the length and thickness of the graphite flakes. Very careful metallographic technique is re-

¹ Superior numbers refer to bibliography.

quired to reveal the true thickness of the flakes, and their actual measurement is extremely difficult under the most ideal conditions. The method seems too tedious for ordinary use.

5. Portevin advanced the following suggestion for the classification of graphite flake sizes. He proposes that a ruled net be placed over a micrograph, at 100 diameters, and the number of flakes counted that do not cut a cross line, that cut one line, and that cut two, three, etc. lines. The results are then put in tabular form for comparison. Actually, such a table is scarcely as illuminating as the micrograph itself.

6. While Mahin and Hamilton did not attempt to establish a correlation between strength and structure, they presented standard flake-size and flake-type micrographs for use in classifying cast iron structures. Their method, subsequently adopted as a tentative recommended practice after minor revisions by a joint committee of the A. S. T. M. and the A. F. A.⁴, appears to be the most practical. However, in the application of this general method as a basis for the correlation of strength and structure, certain modifications seem desirable.

Graphite Formation Mechanisms

7. As it now stands, the method described in A.S.T.M. tentative recommended practice for evaluating the microstructure of graphite in gray cast iron, A247-41T, is designed to be used as a means of describing the structure which appears in a given micro-section. Graphite structures are classified into five general types. To be sure, all of the configurations are often observed. However, in utilizing this classification to develop the relation between the strength and the structure of an iron with a given chemical composition, only the graphite patterns which result from different freezing mechanisms seem to be particularly important. The appearance of the other patterns probably depends upon one or more of the following factors: carbon content, cell size, and the "chance" element in sectioning.

8. From the standpoint of graphite formation, only two types appear to be required. These types are illustrated by Figs. 1 and 2. Boyles⁵ has demonstrated that normal flakes, Type A, are formed during the freezing of the eutectic. Solid dendrites of primary austenite already exist in the melt at the time the eutectic liquid solidifies; so the flakes are necessarily relegated to a certain degree

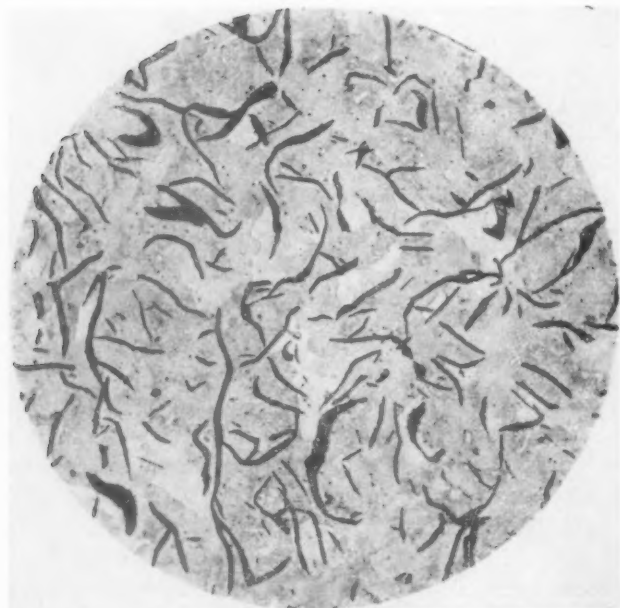


FIG. 1—TYPE A, NORMAL, UNORIENTED GRAPHITE FLAKES. MAGNIFICATION, x100.

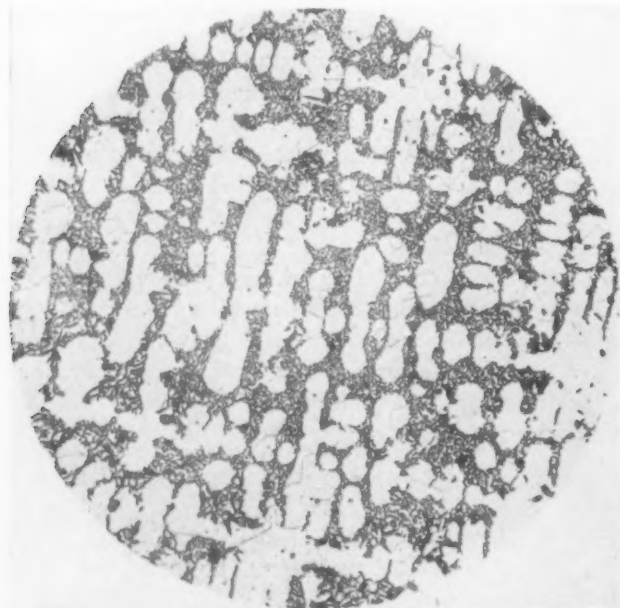


FIG. 2—TYPE B, EUTECTIFORM GRAPHITE. MAGNIFICATION, x100.

of dendritic orientation. The apparentness of this orientation depends upon the composition of the iron and the "chance" element of sectioning.

9. At the same time, the mechanism of eutectic solidification results in another pattern effect. The eutectic begins to freeze at centers of crystallization which are independent of the primary dendrites, and the flakes grow radially from these centers insofar as obstruction by the dendritic skeletons will permit, resulting in a "rosette" pattern. This mechanism is plainly illustrated by Fig. 3. If the centers of nucleation are rather widely separated, each "rosette" unit will be relatively large and the pattern formed will tend to be well defined. If, on the other hand, there are many centers of crystallization and each cell is small, this pattern will not be so distinct. The rosette pattern tends to be more apparent in high carbon irons because the primary dendrites form less discontinuities in the outline. Thus it can be seen that, at least as far as flake formation is concerned, both the dendritic and the rosette patterns are a result of the normal solidification of cast iron and, for purposes of correlation, may be classified as Type A.

10. Type B, eutectiform graphite, may be formed in a some-

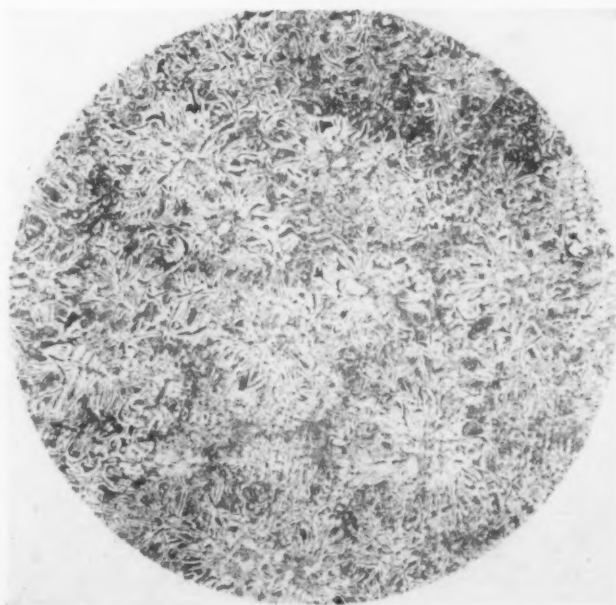


FIG. 3—GRAPHITE IN ROSETTE PATTERN, MAGNIFICATION, $\times 20$.

what different manner. This eutectiform graphite is similar to the A. S. T. M.—A. F. A. Type *D*. In the A. S. T. M.—A. F. A. classification, this type is called "Inter-Dendritic Segregation, Random Orientation"; however, since all graphite is interdendritic, the use of "eutectiform" or some other word seems preferable. Eash⁶ has postulated, as have many other investigators, that these finely divided flakes result from the decomposition of eutectic carbide which originally solidified in the metastable iron-graphite system as white iron. Boyles⁵ has proposed the theory that this configuration may result when the carbide is either very stable or very unstable. However, whichever theory is accepted, it should be quite apparent that the eutectiform structure is formed under quite different freezing conditions than normal graphite and, therefore, should be considered as a separate, distinct type.

Suggested Methods for Comparing Graphite Flake Size

11. For the determination of graphite size, Mahin and Hamilton suggest the use of magnifications of 25 diameters in conjunction with either an ocular device or a standard mounted next to the specimen on the microscope stage. The A. S. T. M.—A. F. A.



FIG. 4—GRAPHITE SIZE No. 4. MAGNIFICATION, $\times 100$.



FIG. 5—GRAPHITE SIZE No. 5. MAGNIFICATION, x100.



FIG. 6—GRAPHITE SIZE No. 6. MAGNIFICATION, x100.

method proposes that the classification be made either by use of a standard ocular, similar to the grain size ocular now in use, or by direct comparison of the image of the section, at a magnification of 100 diameters, with the standard graphite size chart.

Selection of Fields

12. Experience in grain size estimation in steel has shown that the eye can make comparisons with the A. S. T. M. standard chart with almost the same accuracy from a single glance as can be obtained by tedious counting or by use of the ocular. A similar technique is used in determining paper fibers under the microscope by comparison with known fiber mixtures. Therefore, in the work to be reported below, a preliminary examination at 25 diameters was used to select a thoroughly representative field; the magnification was then stepped up to 100 diameters, and a comparison made with the standard micrographs. These micrographs are shown in Figs. 4 to 8 and are comparable to the corresponding size numbers in the A. S. T. M.—A. F. A. proposed classification. Examination at 100 diameters is preferred because of the general use of this magnification in grain size determinations on steel. If this value is used, the observer accustomed to working on steel does not have to shift his point of view. The graphite size numbers and the grain size numbers for steel then remain comparable.

13. Only a cursory attempt to correlate graphite size and type with strength is required to indicate that the degree of correlation is not particularly high. For example, two irons of very similar chemical compositions may have Type A graphite, Size 4, and have tensile strengths of either 40,000 or 25,000 lb. per sq. in. (Table 12, Specimens 3636-3 and 3131-3); or, in another composition (Table 14, Specimens 912 and 1919-1), one iron with Type A graphite of Size 5 may show 35,000 lb. per sq. in. while another with Type A graphite of Size 4-5 instead of being weaker, as a result of the coarser graphite, gives 44,000 lb. per sq. in.

Methods of Determining Cell Size

14. Further investigation indicated that cell size, as well as graphite size, is an important factor influencing the strength of cast iron. The growth of these cells from centers of crystallization during the freezing of the eutectic has been mentioned previously. Since the cell boundaries are the last portion of the iron to freeze, and consequently the lower melting constituents tend to be con-

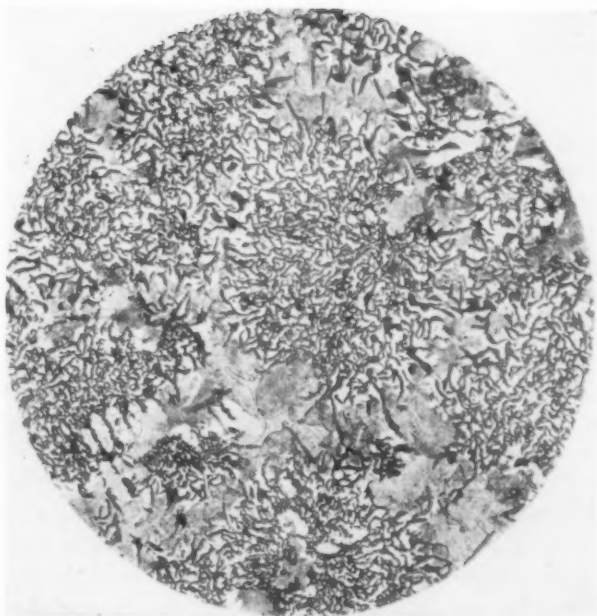


FIG. 7—GRAPHITE SIZE No. 7. MAGNIFICATION, $\times 100$.

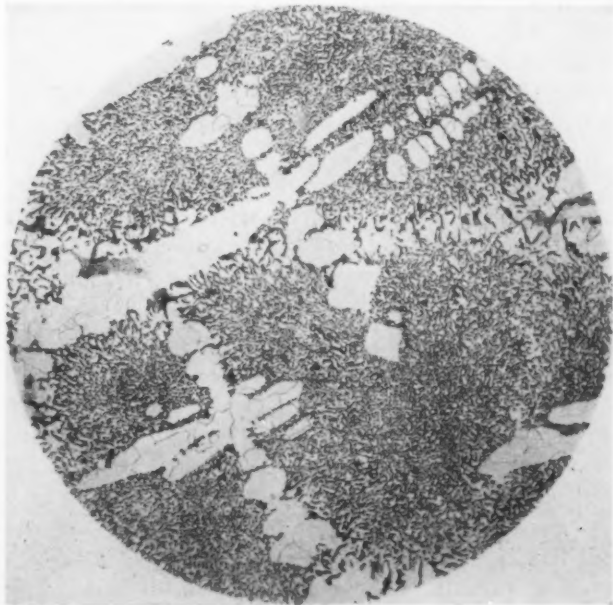


FIG. 8—GRAPHITE SIZE No. 8. MAGNIFICATION, $\times 100$.

centrated in these regions, the segregation of phosphorus may be at least partially responsible for the effect on the strength. The extent to which the phosphide eutectic causes discontinuities in the matrix of the iron will depend, at least in part, upon the size of the cells. This cell size can sometimes, especially in high phosphorus irons, be revealed by heat tinting; that is, developing a temper color on a clean polished specimen by heating in air and quenching in mercury as soon as the proper degree of color contrast has been attained. Deep etching in an alcoholic solution containing 25 per cent of concentrated nitric acid will also disclose the cell size in some high phosphorus irons.

15. The method most universally applicable, particularly on pearlitic irons, is to heat for $\frac{1}{2}$ to 2 hours at a temperature slightly below the critical; i.e., at 1300°F. The time of treatment has to be determined by trial and error. The pearlite in the center of the cells, being purer than that at the edge, tends to break down more rapidly than that at the periphery, leaving the cells outlined by undecomposed pearlite. The segregation of phosphorus at the cell boundaries may be partly responsible for the increased stability in that locality. Hayes* has indicated that phosphorus retards graphitization at temperatures below the critical.

Suggested Cell Size Chart

16. The cell structure may be quite coarse. To meet this situation, and still refer the sizes back to a standard similar to that established by the A. S. T. M. for grain size estimation, the examination is made at 25 diameters. The cell size chart is shown in Fig. 9. The same technique is used in determining cell size as is used in the estimation of grain size in steel. Cell sizes of 1 to 6 were met in the irons studied. Figure 10 illustrates the cell configuration as revealed by heat tinting. Figure 11 shows the phosphorus segregation at the cell boundaries as revealed by a deep nital etch. The specimen shown in Fig. 12 was heated for $1\frac{1}{2}$ hours at a temperature of 1300°F. In this case, the cells are outlined by bands of undecomposed pearlite.

Structural Characteristics Influencing Strength

17. If cell size is taken as one of the primary factors, with a small cell size required for high strength, irons of a given class as to chemical composition may be arranged on the basis of structure

* U. S. Patent No. 1,801,742.

into the expected order of strength. The following structural characteristics are considered in the order listed: (1) Irons with small cell size should have the greatest strength, (2) pearlitic irons with Type *A* graphite should be stronger than those with Type *B* graphite, (3) small flakes should confer greater strength than large flakes regardless of the type, and (4) irons showing free ferrite should

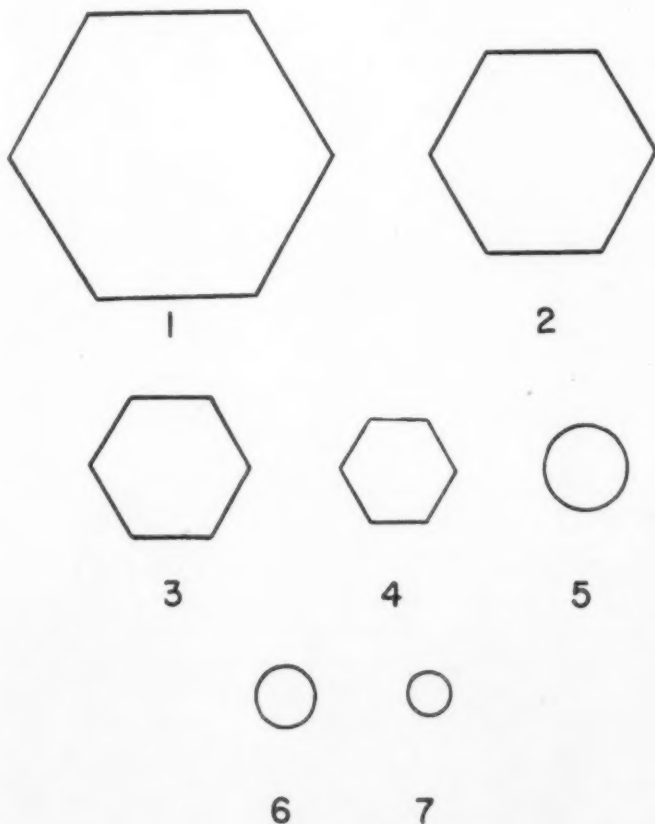


FIG. 9—CELL SIZE STANDARD FOR USE AT A MAGNIFICATION OF 25.

be very weak. If the strength to be evaluated is tensile strength, as determined on the central portion of an end of a broken transverse arbitration bar, then the structure to compare is that of the center. On the other hand, if the strength is to be evaluated on the basis of the transverse test, the structure at the edge, where the



FIG. 10—CELL CONFIGURATION AS REVEALED BY HEAT TINTING. MAGNIFICATION, $\times 25$.

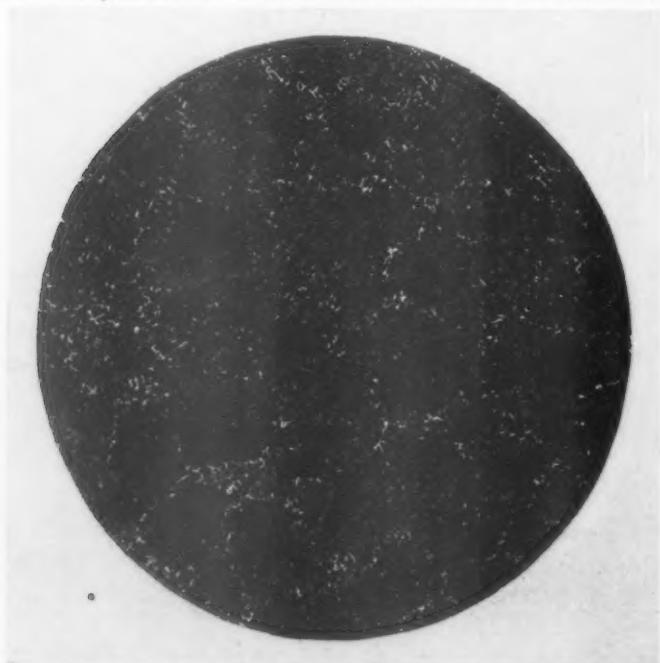


FIG. 11—CELL CONFIGURATION AS REVEALED BY DEEP ETCHING. MAGNIFICATION, $\times 25$.

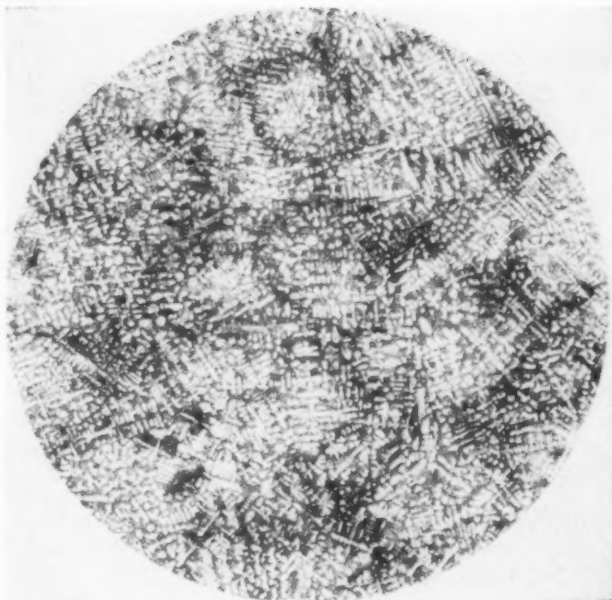


FIG. 12—CELL CONFIGURATION AS REVEALED BY HEAT TREATMENT AT 1300°F. MAGNIFICATION, x25.

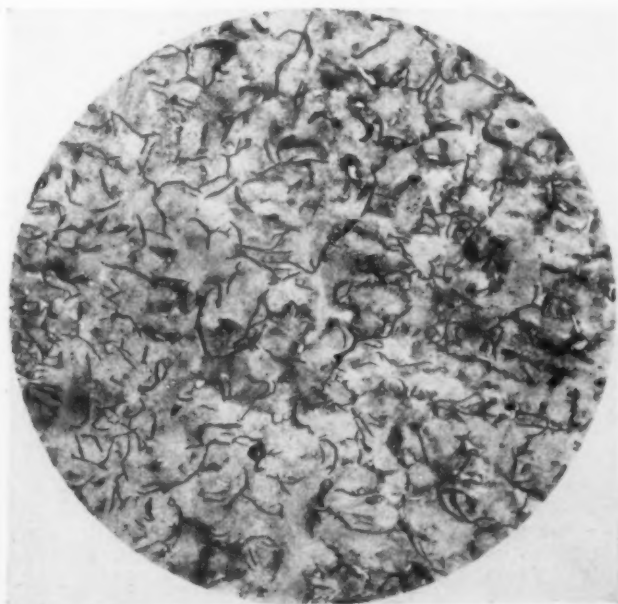


FIG. 13—SPECIMEN No. 5252-2—CELL SIZE No. 6; GRAPHITE, TYPE A, SIZE 6; TENSILE STRENGTH 54,000 LB. PER SQ. IN. MAGNIFICATION, x100.

maximum stress comes in the transverse test, is the one to be compared.

COMPARISONS OF STRENGTH AND STRUCTURE

18. A comparison of tensile strength was made on 176 specimens; 162 of these were classified on the basis of transverse strength, the other 14 being bars of other than the regular 1.2-in. diameter and therefore not comparable in transverse strength. The irons were sorted into 5 groups according to carbon and silicon content. Within each group, the samples were listed in order of expected tensile or transverse strength. If the criteria of evaluation on the primary basis of cell size and on the secondary basis of graphite characteristics are sound, the lists should then start with the iron of highest strength and end with that of lowest strength.

Composition of Irons

19. As the tables of compositions show, all the irons studied are plain, unalloyed irons, ordinarily running not far from 0.70 per

Table 1

CHEMICAL ANALYSIS OF CAST IRONS CLASSIFIED

*Analysis Range: 2.80-2.90 Percent Total Carbon,
2.05-2.25 Percent Silicon*

Specimen No.	Composition, Percent				
	Total Carbon	Silicon	Manganese	Sulphur	Phosphorus
163	2.80	2.05	0.77	0.053	0.093
99	2.80	2.12	0.71	0.079	0.124
155	2.80	2.22	0.73	0.060	0.096
153	2.81	2.10	0.73	0.060	0.096
53	2.81	2.13	0.76	0.063	0.099
15	2.83	2.13	0.69	0.059	0.110
100	2.83	2.13	0.71	0.079	0.124
E1-1*	2.84	2.12	0.68		
E1-2*	2.84	2.12	0.68		
E1-3*	2.84	2.12	0.68		
226	2.84	2.12	0.72	0.046	0.095
223	2.84	2.19	0.72	0.046	0.095
52	2.85	2.13	0.76	0.063	0.099
222	2.86	2.12	0.72	0.046	0.095
221	2.86	2.15	0.72	0.046	0.095
210	2.86	2.15	0.74	0.056	0.097
152	2.87	2.11	0.68	0.064	0.098
47	2.87	2.17	0.76	0.064	0.093
162	2.88	2.07	0.77	0.053	0.093
209	2.88	2.14	0.74	0.056	0.097
51	2.90	2.12	0.76	0.063	0.099
71	2.90	2.19	0.74	0.064	0.093

*—1 indicates 0.875-in. diameter bar; —2 indicates 1.2-in. diameter bar; —3 indicates 2.0-in. diameter bar.

Table 2

CHEMICAL ANALYSIS OF CAST IRONS CLASSIFIED

*Analysis Range: 2.90-3.00 Percent Total Carbon,
2.05-2.35 Percent Silicon*

Specimen No.	Composition, Percent				
	Total Carbon	Silicon	Manganese	Sulphur	Phosphorus
51	2.90	2.12	0.76	0.063	0.099
71	2.90	2.19	0.74	0.064	0.093
5252-1*	2.91	2.05	0.55	0.100	0.220
5252-2*	2.91	2.05	0.55	0.100	0.220
83	2.91	2.15	0.72	0.020	0.093
172	2.91	2.15	0.72	0.055	0.093
211	2.91	2.15	0.74	0.056	0.097
190	2.92	2.15	0.75	0.056	0.092
197	2.92	2.15	0.75	0.056	0.092
C1	2.93	2.05	0.66		
212	2.93	2.12	0.74	0.056	0.097
213	2.93	2.14	0.74	0.056	0.097
89	2.93	2.18	0.76	0.096	0.098
46	2.93	2.19	0.76	0.064	0.093
171	2.94	2.11	0.72	0.055	0.093
157	2.94	2.11	0.73	0.055	0.093
81	2.95	2.12	0.72	0.020	0.093
182	2.95	2.17	0.73	0.049	0.094
191	2.95	2.18	0.75	0.056	0.092
45	2.95	2.18	0.76	0.064	0.093
160	2.95	2.25	0.72	0.056	0.094
184	2.95	2.26	0.76	0.059	0.093
185	2.95	2.28	0.76	0.069	0.093
167	2.96	2.09	0.74	0.055	0.095
151	2.96	2.12	0.68	0.064	0.098
82	2.96	2.14	0.72	0.020	0.093
165	2.96	2.14	0.74	0.055	0.095
214	2.96	2.15	0.74	0.056	0.097
192	2.96	2.17	0.75	0.056	0.092
70	2.96	2.19	0.74	0.064	0.093
69	2.96	2.19	0.74	0.064	0.093
166	2.97	2.08	0.74	0.055	0.095
187	2.97	2.26	0.76	0.059	0.093
183	2.97	2.28	0.76	0.059	0.093
159	2.97	2.29	0.72	0.056	0.094
158	2.97	2.35	0.73	0.055	0.093
156	2.98	2.05	0.73	0.055	0.093
161	2.98	2.23	0.72	0.056	0.094
135	2.98	2.26	0.68	0.099	0.090
85	2.99	2.11	0.72	0.078	0.096
84	2.99	2.16	0.72	0.078	0.096
194	2.99	2.16	0.75	0.056	0.092
193	2.99	2.17	0.75	0.056	0.092
113	2.99	2.21	0.70	0.052	0.091
181	3.00	2.18	0.73	0.049	0.094
137	3.00	2.23	0.68	0.100	0.090
86	3.00	2.14	0.72	0.078	0.096
186	3.00	2.26	0.76	0.059	0.093
188	3.00	2.29	0.76	0.059	0.093

*—1 indicates 0.875-in. diameter bar; —2 indicates 1.2-in. diameter bar.

Table 3

CHEMICAL ANALYSIS OF CAST IRONS CLASSIFIED

*Analysis Range: 3.00-3.15 Percent Total Carbon,
2.05-2.35 Percent Silicon*

Specimen No.	Composition, Percent				
	Total Carbon	Silicon	Manganese	Sulphur	Phosphorus
86	3.00	2.14	0.72	0.078	0.096
137	3.00	2.23	0.68	0.100	0.090
186	3.00	2.26	0.76	0.059	0.093
188	3.00	2.29	0.76	0.059	0.093
26	3.01	2.14	0.60	0.056	0.090
180	3.01	2.17	0.73	0.049	0.094
132	3.01	2.32	0.78	0.062	0.091
75	3.02	2.24	0.76	0.059	0.095
25	3.03	2.14	0.70	0.056	0.090
62	3.03	2.21	0.72	0.062	0.094
136	3.03	2.23	0.68	0.098	0.090
149	3.03	2.34	0.70	0.063	0.097
59	3.04	2.12	0.69	0.064	0.091
57	3.04	2.15	0.69	0.064	0.091
76	3.04	2.20	0.76	0.059	0.095
77	3.04	2.21	0.76	0.059	0.095
114	3.04	2.25	0.71	0.062	0.090
173	3.04	2.25	0.72	0.055	0.093
146	3.05	2.19	0.61	0.310	0.090
A2-1*	3.05	2.23	0.57	0.053	0.052
A4-2*	3.05	2.23	0.57	0.053	0.052
147	3.06	2.13	0.70	0.063	0.097
111	3.06	2.22	0.70	0.052	0.091
115	3.06	2.23	0.71	0.062	0.090
129	3.06	2.26	0.75	0.058	0.090
127	3.06	2.27	0.76	0.056	0.090
133	3.06	2.29	0.78	0.062	0.091
145	3.07	2.21	0.61	0.310	0.090
112	3.07	2.22	0.70	0.052	0.091
148	3.07	2.24	0.70	0.063	0.097
116	3.07	2.26	0.71	0.062	0.090
128	3.07	2.35	0.76	0.056	0.090
58	3.08	2.11	0.69	0.064	0.091
60	3.08	2.15	0.72	0.062	0.094
61	3.08	2.16	0.72	0.062	0.094
144	3.08	2.22	0.61	0.300	0.090
141	3.08	2.23	0.70	0.210	0.091
139	3.08	2.25	0.62	0.190	0.089
140	3.08	2.25	0.62	0.230	0.089
126	3.08	2.34	0.76	0.056	0.090
138	3.09	2.21	0.62	0.140	0.089
143	3.10	2.23	0.70	0.210	0.091
130	3.10	2.35	0.75	0.058	0.090
142	3.12	2.23	0.70	0.210	0.091
134	3.12	2.29	0.78	0.062	0.091
54	3.15	1.87	0.74	0.067	0.098
98	3.15	1.93	0.64	0.077	0.139

*—1 indicates 0.875-in. diameter bar; —2 indicates 1.2-in. diameter bar.

Table 4

CHEMICAL ANALYSIS OF CAST IRONS CLASSIFIED

*Analysis Range: 3.15-3.30 Percent Total Carbon,
1.85-2.15 Percent Silicon*

Specimen No.	Composition, Percent				
	Total Carbon	Silicon	Manganese	Sulphur	Phosphorus
54	3.15	1.87	0.74	0.067	0.098
3636-1*	3.15	1.93	0.55	0.100	0.220
3636-2*	3.15	1.93	0.55	0.100	0.220
3636-3*	3.15	1.93	0.55	0.100	0.200
98	3.15	1.93	0.64	0.077	0.139
80	3.16	1.89	0.72	0.058	0.094
74	3.19	1.90	0.71	0.063	0.093
48	3.21	1.86	0.72	0.059	0.094
179	3.21	1.90	0.70	0.055	0.096
68	3.22	1.86	0.69	0.063	0.096
95	3.23	1.90	0.60	0.082	0.124
119	3.23	1.95	0.67	0.059	0.090
3131-1*	3.23	2.01	0.75	0.102	0.107
3131-2*	3.23	2.01	0.75	0.102	0.107
3131-3*	3.23	2.01	0.75	0.102	0.107
3939-1*	3.23	2.02	0.73	0.097	0.110
3939-2*	3.23	2.02	0.73	0.097	0.110
3939-3*	3.23	2.02	0.73	0.097	0.110
177	3.24	1.88	0.70	0.055	0.096
79	3.24	1.88	0.72	0.058	0.094
96	3.25	1.93	0.64	0.077	0.139
114	3.25	2.00	0.69	0.076	0.146
67	3.26	1.91	0.69	0.063	0.096
117	3.26	1.93	0.67	0.059	0.090
178	3.27	1.87	0.70	0.055	0.096
78	3.27	1.88	0.72	0.058	0.094
72	3.27	1.90	0.71	0.063	0.093
97	3.27	1.91	0.64	0.077	0.139
66	3.28	1.85	0.69	0.063	0.096
73	3.28	1.91	0.71	0.063	0.093
94	3.29	1.88	0.60	0.082	0.142
176	3.29	1.88	0.66	0.050	0.095
174	3.29	1.89	0.66	0.050	0.095
513	3.29	1.92	0.66	0.085	0.156
92	3.29	1.95	0.62	0.075	0.142
124	3.29	2.00	0.69	0.057	0.092
123	3.29	2.04	0.69	0.057	0.092
013	3.30	1.91	0.69	0.079	0.152
125	3.30	2.07	0.69	0.057	0.092

*—1 indicates 0.875-in. diameter bar; —2 indicates 1.2-in. diameter bar; —3 indicates 2.0-in. diameter bar.

Table 5
CHEMICAL ANALYSIS OF CAST IRONS CLASSIFIED
Analysis Range: 3.30-3.45 Percent Total Carbon;
1.85-2.15 Percent Silicon

Specimen No.	Composition, Percent				
	Total Carbon	Silicon	Manganese	Sulphur	Phosphorus
013	3.30	1.91	0.69	0.079	0.151
125	3.30	2.07	0.69	0.057	0.092
122	3.31	1.96	0.68	0.057	0.090
90	3.31	1.98	0.62	0.075	0.142
213	3.31	1.98	0.65	0.084	0.141
175	3.32	1.90	0.66	0.050	0.095
91	3.32	1.93	0.62	0.075	0.142
412	3.32	2.00	0.63	0.081	0.141
93	3.33	1.87	0.60	0.082	0.142
912	3.33	1.92	0.71	0.079	0.153
118	3.33	1.94	0.67	0.059	0.090
121	3.33	1.97	0.68	0.057	0.090
33	3.34	2.14	0.69	0.061	0.092
813	3.35	2.00	0.71	0.079	0.151
120	3.35	1.97	0.68	0.057	0.090
1919-1*	3.36	1.84	0.55	0.100	0.220
1919-2*	3.36	1.84	0.55	0.100	0.220
1919-3*	3.36	1.84	0.55	0.100	0.220
313	3.37	1.96	0.69	0.081	0.142
40	3.40	2.09	0.67	0.067	0.106
39	3.45	2.12	0.67	0.067	0.106

cent manganese and 0.10 per cent phosphorus, although there are some 0.15 per cent phosphorus and a couple of 0.22 per cent phosphorus irons in the list. A change in the matrix resulting from the introduction of alloying elements, or of phosphorus in considerable amounts, may alter the evaluation by introducing other factors than those of cell size and graphite characteristics which were considered in this investigation.

DISCUSSION OF RESULTS

20. Tables 1 to 5 show the chemical analyses of the cast irons classified. The resulting correlation between the structural classification and the mechanical properties is shown in Tables 6 to 15. Examination of these tables will show that, while the correlation is not perfect, an excellent indication of the strength of an iron can be gained from a consideration of its structure.

21. The tabular method of presentation is not entirely desirable because of the complexity of the subject. For example, the amount of Type *B* graphite in Specimen 135 (Table 8) is sufficient to cause

*—1 Indicates 0.875-in. diameter bar; --2 Indicates 1.2-in. diameter bar; —3 Indicates 2.0-in. diameter bar.

Table 6

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TENSILE STRENGTH

Analysis Range: 2.80-2.90 Percent Total Carbon,
2.05-2.25 Percent Silicon

Specimen No.	Cell Size	Graphite Type		Graphite Size		Average Tensile Strength, lb. per sq. in.	Tensile Strength Range, lb. per sq. in.	Brinell Hardness
		Center	Edge	Center	Edge			
223	6	A	A	5-6	5-6	51,000	48,000-52,000	220
222	6	A	A	5	5-6	52,500	50,000-53,000	216
221	6	A	A	5	5-6	48,000	47,500-48,500	212
162	6	A	A	5	5-6	48,000	47,500-48,500	197
226	6	A	A	5	5	45,000	45,000-45,000	204
155	6	A	A	4-5	5	51,000	49,000-52,000	208
E1-2	6	A-B	A-B	6-7	8	44,500	42,500-46,000	255
153	5	A	A	5-6	5	48,500	48,000-49,500	205
163	5	A	A	5	5	48,000	47,000-48,500	202
152	5	A	A	4-5	5	44,000	42,500-44,500	196
E1-1	4	A	B	5-6	8	48,000	47,500-49,000	263
210	3	A	A-B	5-6	7-8	40,500	39,500-41,500	215
100	3	A	A-B	5-6	6-7	38,000	37,500-39,000	201
99	3	A	A	5	6	39,500	38,000-40,000	199
209	3	A	B	5	8	37,500	37,000-38,000	215
E1-3	3	A	A	4	5	37,500	36,000-39,000	234
53	3	B	B	8	8	36,000	35,500-36,000	214
52	3	B	B	8	8	35,500	34,000-36,000	206
51	2	A	B	5-6	8	35,000	34,000-36,000	202
47	2	A	B	5	8	34,500	34,000-36,000	209
15	2	B	B	8	8	34,000	32,000-35,000	215
71	2	B	B	8	8	32,000	31,500-33,000	189

Table 7

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TRANSVERSE STRENGTH

Analysis Range: 2.80-2.90 Percent Total Carbon,
2.05-2.25 Percent Silicon

Specimen No.	Cell Size	Graphite Type		Graphite Size		Average Transverse Strength, lb.	Transverse Strength Range, lb.	Brinell Hardness
		Edge	Center	Edge	Center			
223	6	A	A	5-6	5-6	2950	2840-3080	220
222	6	A	A	5-6	5	3190	3060-3320	216
162	6	A	A	5-6	5	3190	3050-3290	197
155	6	A	A	5	4-5	3045	2980-3110	208
E1-2	6	A-B	A-B	8	6-7	2730	2560-2780	255
153	5	A	A	5	5-6	3170	3070-3210	205
163	5	A	A	5	5	2970	2800-3100	202
152	5	A	A	5	4-5	2960	2900-3040	196
99	3	A	A	6	5	2720	2600-2810	199
210	3	A-B	A	7-8	5-6	2215	2140-2330	215
100	3	A-B	A	6-7	5-6	2710	2640-2760	201
209	3	B	A	8	5	2360	2300-2470	215
53	3	B	B	8	8	2510	2400-2670	214
52	3	B	B	8	8	2410	2360-2490	206
51	2	B	A	8	5-6	2370	2340-2400	202
47	2	B	A	8	5	2535	2380-2650	209
71	2	B	B	8	8	2500	2400-2660	189
15	2	B	B	8	8	2490	2410-2540	215

Table 8

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TENSILE STRENGTH

*Analysis Range: 2.90-3.00 Percent Total Carbon,
2.05-2.35 Percent Silicon*

Specimen No.	Cell Size	Graphite Type		Graphite Size		Average Tensile Strength, lb. per sq. in.	Tensile Strength Range, lb. per sq. in.	Brinell Hardness
		Center	Edge	Center	Edge			
5252-1	6	A	A	6	7	61,000	60,250-61,500	243
5252-2	6	A	A	6	6	54,000	53,200-54,700	233
190	6	A	A	6	6	44,000	43,000-44,500	216
158	6	A	A	5	6	45,500	45,500-45,500	200
191	6	A	A	5	5-6	44,000	43,000-44,500	215
151	6	A	A	4-6	5	43,000	42,500-43,000	199
C1	6	A	A	4-5	6	42,500	42,000-42,500	238
161	6	A	A	4-5	5-6	42,000	40,500-43,000	192
192	6	A	A	4-5	5-6	41,500	40,000-43,000	208
160	6	A	A	4-5	5	42,000	40,500-42,500	191
188	6	A-B	B	6-7	7	35,500	35,000-36,000	208
212	5	A	A	5	6	41,500	40,500-42,000	188
157	5	A	A	5	6	41,400	41,000-42,500	200
135	5	A	A-B	5	6-7	32,500	32,000-32,500	180
194	5	A	A	4-5	6	41,000	39,000-44,000	217
214	5	A	A-B	4-5	6-7	38,500	36,000-40,600	209
137	5	A-B	B	5-8	8	33,000	32,500-34,000	186
211	4	A	A	5-6	6	41,000	39,000-41,500	213
193	4	A	A	5	6	40,500	39,500-41,000	217
159	4	A	A	5	5-6	41,000	40,000-42,000	190
213	3	A	A	5-6	6	38,500	38,000-40,000	204
167	3	A	A	4-6	6	38,000	37,000-39,000	200
181	3	A	A	5	6	37,500	36,500-38,500	201
166	3	A	A	4-5	6	37,000	36,000-37,500	199
83	3	A	B	4-5	8	36,000	35,000-36,500	195
81	3	A	B	4-5	8	34,000	32,500-35,500	199
187	3	A-B	B	6-8	8	35,500	35,000-36,000	208
172	3	A-B	B	6-8	8	35,500	35,000-36,000	207
171	3	A-B	B	6-8	8	35,000	34,500-35,000	201
82	3	A-B	B	5-8	8	34,000	32,000-35,000	199
45	2	A	B	6	8	34,500	32,500-37,500	209
51	2	A	B	5-6	8	35,000	34,000-36,000	202
156	2	A	A	5	6	35,000	34,000-36,000	194
165	2	A	A	4-6	6	35,000	35,000-35,000	192
186	2	A-B	B	6-8	8	34,000	33,500-34,000	204
85	2	A-B	B	6-8	8	32,500	32,000-33,500	192
86	2	A-B	B	6-8	8	32,000	31,500-33,000	188
182	2	A-B	B	6-7	8	34,000	33,000-35,500	206
46	2	A-B	B	6-7	8	32,600	31,500-33,500	190
84	2	A-B	B	5-7	8	32,000	31,000-33,000	195
185	2	B	B	8	8	34,000	33,500-34,000	204
184	2	B	B	8	8	34,000	33,500-34,500	191
71	2	B	B	8	8	32,000	31,500-33,000	189
70	2	B	B	8	8	31,500	31,000-33,000	189
183	2	B	B	8	8	31,000	31,000-31,500	191
69	2	B	B	8	8	30,000	29,500-31,500	184
89	1	A-B	B	6-8	8	31,500	31,000-32,000	193
113	1	A-B	B	6-7	8	31,500	31,000-32,000	192

Table 9

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TRANSVERSE STRENGTH

*Analysis Range: 2.90-3.00 Percent Total Carbon,
2.05-2.35 Percent Silicon*

Specimen No.	Cell Size	Graphite Type Edge Center	Graphite Size Edge Center	Average Transverse Strength, lb.	Transverse Strength Range, lb.	Brinell Hardness
5252-2	6	A A	6 6	3400	3360-3450	233
190	6	A A	6 6	2830	2720-2880	216
158	6	A A	6 5	3055	3030-3100	200
C1	6	A A	6 4-5	2632	2410-2760	238
191	6	A A	5-6 5	2730	2680-2810	215
161	6	A A	5-6 4-5	2830	2740-2920	192
192	6	A A	5-6 4-5	2670	2600-2780	208
151	6	A A	5 4-6	2840	2770-2940	199
160	6	A A	5 4-5	2690	2640-2720	191
188	6	B A-B	7 6-7	2470	2330-2560	208
157	5	A A	6 5	2900	2870-2940	200
212	5	A A	6 5	2350	2300-2490	188
194	5	A A	6 4-5	2780	2730-2830	217
135	5	A-B A	6-7 5	2405	2340-2470	180
214	5	A-B A	6-7 4-5	2170	2050-2310	209
137	5	B A-B	8 5-8	2330	2240-2430	186
211	4	A A	6 5-6	2090	1990-2180	213
193	4	A A	6 5	2850	2840-2860	217
159	4	A A	5-6 5	2920	2900-2960	190
213	3	A A	6 5-6	2180	2120-2250	204
167	3	A A	6 4-6	2720	2620-2820	200
181	3	A A	6 5	2560	2520-2660	201
166	3	A A	6 4-5	2780	2690-2880	199
83	3	B A	8 4-5	2390	2260-2490	195
81	3	B A	8 4-5	2245	2180-2330	199
187	3	B A-B	8 6-8	2520	2510-2560	208
171	3	B A-B	8 6-8	2500	2430-2600	201
172	3	B A-B	8 6-8	2485	2420-2520	207
82	3	B A-B	8 5-8	2350	2250-2430	199
156	2	A A	6 5	2870	2830-2960	194
165	2	A A	6 4-6	2885	2820-2960	192
45	2	B A	8 6	2470	2245-2540	209
51	2	B A	8 5-6	2370	2340-2400	202
186	2	B A-B	8 6-8	2600	2320-2720	204
86	2	B A-B	8 6-8	2350	2230-2450	188
85	2	B A-B	8 6-8	2320	2280-2340	192
46	2	B A-B	8 6-7	2540	2420-2600	190
182	2	B A-B	8 6-7	2430	2380-2490	206
84	2	B A-B	8 5-7	2310	2220-2370	195
184	2	B B	8 8	2750	2740-2810	191
185	2	B B	8 8	2670	2560-2780	204
183	2	B B	8 8	2580	2470-2700	191
71	2	B B	8 8	2500	2400-2660	189
69	2	B B	8 8	2355	2210-2450	184
70	2	B B	8 8	2310	2210-2500	189
89	1	B A-B	8 6-8	2430	2330-2560	193
113	1	B A-B	8 6-7	2420	2290-2590	192

Table 10

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TENSILE STRENGTH

*Analysis Range: 3.00-3.15 Percent Total Carbon,
2.05-2.35 Percent Silicon*

Speci- men No.	Cell Size	Graphite Type		Graphite Size		Average Tensile Strength, lb. per sq. in.	Tensile Strength Range, lb. per sq. in.	Brinell Hardness
		Center	Edge	Center	Edge			
149	6	A	A	5	6	41,000	40,500-41,000	192
148	6	A	A	5	6	39,500	38,500-40,000	189
114	6	A	A	5	6	36,500	35,000-37,000	183
127	6	A	A	4-6	6	36,000	35,500-37,000	195
58	6	A	A	5	5	34,500	34,000-35,000	189
134	6	A	B	5	8	35,000	34,000-36,000	198
147	6	A	A	4-5	6	35,500	35,000-36,500	188
180	6	A	A	4-5	5	38,500	38,000-39,000	194
57	6	A	A	4-5	5	37,000	36,000-37,500	190
128	6	A	B	4-5	8	35,000	33,500-36,500	194
188	6	A-B	B	6-7	7	35,500	35,000-36,000	208
54	5	A-B	A-B	6-8	6-8	30,000	29,000-30,500	188
137	5	A-B	B	5-8	8	33,000	32,500-34,000	186
144	4	A	B	5-6	7	33,500	32,500-34,000	190
143	4	A	B	5-6	7	33,500	32,000-34,000	186
145	4	A	B	5-6	7	32,500	32,000-34,000	188
140	4	A	B	5	6-8	31,500	31,000-32,000	178
142	4	A	B	5	7	30,500	29,500-31,000	180
141	4	A	B	5	7	30,500	30,000-31,000	165
A4-2	3	A	A	6	6	44,500	43,500-45,500	252
126	3	A	A	6	6	37,000	36,500-37,000	195
A2-1	3	A	A-B	6	6-8	46,000	44,500-48,000	249
173	3	A	B	5-7	7	35,500	35,500-36,500	193
146	3	A	B	5-7	5-8	34,500	33,500-35,000	183
59	3	A	B	4-7	6-8	34,000	32,000-36,500	180
98	3	A	B	5	8	32,500	31,000-33,500	195
111	3	A-B	B	6-7	7	32,500	32,000-33,500	196
136	3	A-B	B	6-7	7	31,000	31,000-31,500	182
139	3	A-B	B	6-7	7	30,000	30,000-30,500	166
112	3	A-B	B	6-7	7	29,000	28,500-29,500	176
138	3	A-B	B	6-7	7	28,500	28,000-30,000	162
25	2	A	B	5-7	8	34,500	33,500-35,500	208
130	2	A	B	5-7	8	34,500	34,000-35,500	199
129	2	A	B	4-5	6-7	34,500	33,500-36,000	194
186	2	A-B	B	6-8	8	34,000	33,500-34,000	204
132	2	A-B	B	6-8	8	34,000	33,000-34,500	203
133	2	A-B	B	6-8	8	33,000	32,500-33,500	198
86	2	A-B	B	6-8	8	32,000	31,500-33,000	188
54	2	B	B	8	8	32,500	31,500-33,500	203
62	2	B	B	8	8	31,000	29,500-32,000	186
77	2	B	B	8	8	30,500	30,000-31,000	185
75	2	B	B	8	8	30,000	29,500-31,000	185
76	2	B	B	8	8	30,000	29,500-30,500	180
60*	6	A	A	4-5	5-6	29,500	28,500-30,500	174
115*	6	A-B	B	6-8	7	29,000	28,000-30,000	178
116*	6	A-B	B	6-8	7	27,500	26,500-29,500	172
61*	3	A	B	5-6	5-8	30,000	29,500-31,500	181

* Appreciable amount of free ferrite.

Table 11

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TRANSVERSE STRENGTH

*Analysis Range: 3.00-3.15 Percent Total Carbon,
2.05-2.35 Percent Silicon*

Speci- men No.	Cell Size	Graphite Type Edge Center	Graphite Size Edge Center	Average Transverse Strength, lb.	Transverse Strength Range, lb.	Brinell Hardness
149	6	A A	6 5	2960	2870-3070	192
148	6	A A	6 5	2920	2860-3020	189
114	6	A A	6 5	2659	2640-2760	183
127	6	A A	6 4-6	2670	2560-2780	195
147	6	A A	6 4-5	2895	2840-2970	188
58	6	A A	5 5	2790	2680-2860	189
57	6	A A	5 4-5	2885	2730-3055	190
180	6	A A	5 4-5	2650	2560-2750	194
134	6	B A	8 5	2350	2280-2420	198
128	6	B A	8 4-5	2520	2490-2580	194
188	6	B A-B	7 6-7	2470	2330-2560	208
54	5	A-B A-B	6-8 6-8	2415	2350-2580	188
137	5	B A-B	8 5-8	2330	2240-2430	186
144	4	B A	7 5-6	2500	2410-2640	190
145	4	B A	7 5-6	2280	2230-2330	188
143	4	B A	7 5-6	2250	2120-2350	186
141	4	B A	7 5	2350	2300-2410	165
142	4	B A	7 5	2215	2170-2310	180
140	4	B A	6-8 5	2190	2060-2280	178
126	3	A A	6 6	2580	2570-2600	195
A4-2	3	A A	6 6	2540	2390-2670	252
98	3	B A	8 5	2300	2260-2330	180
111	3	B A-B	7 6-7	2470	2380-2530	195
112	3	B A-B	7 6-7	2360	2330-2410	176
138	3	B A-B	7 6-7	2360	2280-2450	182
136	3	B A-B	7 6-7	2300	2270-2350	196
139	3	B A-B	7 6-7	2250	2120-2330	182
173	3	B A	7 5-7	2250	2160-2300	193
59	3	B A	6-8 4-7	2800	2715-2880	180
146	3	B A	5-8 5-7	2340	2310-2370	183
130	2	B A	8 5-7	2414	2360-2460	199
25	2	B A	8 5-7	2380	2310-2440	208
186	2	B A-B	8 6-8	2600	2320-2770	204
133	2	B A-B	8 6-8	2380	2310-2440	198
132	2	B A-B	8 6-8	2365	2270-2560	203
86	2	B A-B	8 6-8	2350	2230-2410	188
77	2	B B	8 8	2490	2450-2560	185
76	2	B B	8 8	2470	2400-2560	180
75	2	B B	8 8	2405	2335-2450	185
26	2	B B	8 8	2390	2300-2540	203
62	2	B B	8 8	2355	2260-2365	186
129	2	B A-B	6-7 4-5	2460	2400-2560	194
60*	6	A A	5-6 4-5	2455	2280-2570	174
115*	6	B A-B	7 6-8	2345	2320-2370	178
116*	6	B A-B	7 6-8	2180	2020-2260	172
61*	3	B A	5-8 5-6	2285	2160-2360	181

* Appreciable amount of free ferrite.

Table 12

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TENSILE STRENGTH

*Analysis Range: 3.15-3.30 Percent Total Carbon,
1.85-2.15 Percent Silicon*

Speci- men No.	Cell Size	Graphite Type		Graphite Size		Average Tensile Strength, lb. per sq. in.	Tensile Strength Range, lb. per sq. in.	Brinell Hardness
		Center	Edge	Center	Edge			
3636-1	6	A	A	5	6	50,500	47,750-53,000	225
3636-2	6	A	A-B	5	6-7	46,000	44,300-48,500	208
92	6	A	A-B	4-5	5-7	35,000	34,500-36,000	183
3636-3	6	A	A	4	4-5	40,500	39,300-41,000	205
3939-1	6	A-B	B	6-7	7	39,500	39,000-40,000	197
3131-1	6	A-B	B	6-7	6-7	37,500	37,000-37,750	197
95	6	A-B	B	5-8	7	33,000	32,500-34,000	195
013	5	A	A	5-6	6	35,050	34,300-35,600	193
3939-2	5	A	A	5	6-7	33,900	33,500-34,300	185
117	5	A	A	5	5-6	34,500	34,000-36,000	174
114	5	A	A	5	5	34,900	34,350-35,800	193
94	5	A	A	4-5	5	32,500	32,000-32,500	186
176	5	A	A	4-5	5	32,500	32,000-33,000	172
513	5	A	A	4-6	5	31,925	30,900-33,000	180
119	5	A	A	4-5	5	30,000	30,000-30,500	184
54	5	A-B	A-B	6-8	6-8	30,000	29,000-30,500	188
68	5	A-B	A-B	6-8	6-8	30,000	29,500-30,000	184
125	5	A-B	A-B	6-8	6-8	30,000	29,500-30,000	172
48	5	A-B	B	6-8	8	29,500	28,000-31,000	184
96	5	A-B	B	5-7	6-8	28,000	27,000-29,000	176
124	5	A-B	B	5-7	6-7	28,500	28,000-30,000	170
174	4	A	A	5	6	32,000	31,000-33,000	173
3131-2	4	A	A	5	6	31,600	31,600-31,600	177
3939-3	4	A	A	4-5	5	27,300	27,100-27,500	170
66	4	A	A-B	4-5	5-8	27,500	27,000-28,000	175
74	4	A-B	B	6-8	8	29,500	29,000-30,000	183
80	4	A-B	B	6-8	8	29,500	29,000-30,000	181
79	4	A-B	B	6-8	8	29,000	28,500-29,500	183
73	4	A-B	B	6-8	8	28,500	28,000-29,500	177
98	3	A	B	5	8	32,500	31,000-33,500	195
97	3	A	B	5	8	32,500	31,000-34,000	188
78	3	A	B	5	8	29,000	28,000-29,500	183
177	3	A	A-B	4-6	5	29,000	28,000-30,000	168
178	3	A	A-B	4-6	5	29,000	29,000-29,500	173
123	3	A	B	4-5	7	27,500	26,500-28,000	164
72	3	A-B	A-B	5-7	6-7	28,000	27,000-29,000	175
67	3	A-B	B	5-7	8	27,500	26,000-28,000	174
179	2	A	A-B	4-5	6-8	28,000	27,000-29,000	171
3131-3	2	A	A	4	5	25,350	25,100-25,600	160

the iron to be of relatively low strength; however, because of the necessity of a definite system, this iron had to be listed according to its Size 5 graphite at the center. In actual practice, the classifier would make allowances for the varying percentages of the constituents present. Inclusion of this consideration in the present work would have made the presentation too complicated.

Tensile Strength vs. Structure

22. In general, the tensile strengths line up very well with the structures. Occasional variations will be noted, but these are to be

Table 13

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TRANSVERSE STRENGTH

*Analysis Range: 3.15-3.30 Percent Total Carbon,
1.85-2.15 Percent Silicon*

Specimen No.	Cell Size	Graphite Type Edge	Graphite Type Center	Graphite Size Edge	Graphite Size Center	Average Transverse Strength, lb.	Transverse Strength Range, lb.	Brinell Hardness
3636-2	6	A-B	A	6-7	5	3250	3190-2320	208
92	6	A-B	A	5-7	4-5	2620	2540-2730	183
95	6	B	A-B	7	5-8	2235	2180-2270	195
3939-2	5	A	A	6-7	5	2400	2360-2450	185
O13	5	A	A	6	5-6	2660	2560-2740	193
117	5	A	A	5-6	5	2445	2260-2550	174
114	5	A	A	5	5	2810	2700-2910	193
176	5	A	A	5	4-5	2500	2450-2580	172
513	5	A	A	5	4-5	2440	2390-2500	180
119	5	A	A	5	4-5	2360	2300-2440	184
94	5	A	A	5	4-5	2295	2200-2360	186
54	5	A-B	A-B	6-8	6-8	2415	2350-2580	188
125	5	A-B	A-B	6-8	6-8	2380	2340-2410	172
68	5	A-B	A-B	6-8	6-8	2300	2235-2360	184
48	5	B	A-B	8	6-8	2400	2360-2590	184
96	5	B	A-B	6-8	5-7	2070	2020-2120	176
124	5	B	A-B	6-7	5-7	2330	2280-2410	170
174	4	A	A	6	5	2545	2500-2600	173
3131-2	4	A	A	6	5	2450	2400-2550	177
66	4	A-B	A	5-8	4-5	2185	2130-2240	175
80	4	B	A-B	8	6-8	2365	2240-2500	181
79	4	B	A-B	8	6-8	2345	2235-2400	183
74	4	B	A-B	8	6-8	2340	2240-2400	183
73	4	B	A-B	8	6-8	2320	2220-2340	177
72	3	A-B	A-B	6-7	5-7	2240	2175-2360	175
177	3	A-B	A	5	4-6	2400	2240-2540	168
178	3	A-B	A	5	4-6	2215	2120-2260	173
98	3	B	A	8	5	2300	2260-2330	195
97	3	B	A	8	5	2215	2150-2290	188
78	3	B	A	8	5	2210	2170-2240	183
67	3	B	A-B	8	5-7	2170	2120-2215	174
123	3	B	A	7	4-5	2225	2200-2250	164
179	2	A-B	A	6-8	4-5	2195	2140-2260	171

expected in view of the complexity of cast iron. Phosphorus content up to 0.2 per cent apparently has very little influence on the strength; the major exception being the 1919 series listed in Table 14.

Transverse Strength vs. Structure

23. Transverse strength is not as easily evaluated in terms of structure. While an indication of this property can be obtained from the structure, the scatter is greater than when tensile strength is being considered. This effect probably results from the marked influence of surface characteristics in transverse testing.

Brinell Hardness

24. Brinell hardness apparently depends almost entirely upon

Table 14

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TENSILE STRENGTH

*Analysis Range: 3.30-3.45 Percent Total Carbon,
1.85-2.25 Percent Silicon*

Specimen No.	Cell Size	Graphite Type		Graphite Size		Average Tensile Strength,	Tensile Strength Range,	Brinell Hardness
		Center	Edge	Center	Edge	lb. per sq. in.	lb. per sq. in.	
1919-1	6	A	A	4-5	5-6	44,000	44,000-44,000	203
91	6	A	A	4-5	6	34,000	32,500-35,500	187
120	6	A-B	B	5-7	7	32,000	30,000-33,500	170
Q13	5	A	A	5-6	6	35,050	34,300-35,600	193
813	5	A	A	5	6	34,500	33,900-34,900	186
90	5	A	A	5	5-6	33,000	32,500-33,500	176
175	5	A	A	4-5	5-6	33,000	32,500-33,500	168
1919-2	5	A	A	4-5	5	36,000	35,000-37,600	190
118	5	A	A	4-5	5	31,500	31,000-32,000	173
213	5	A	A-B	4-5	6-7	32,500	31,300-33,100	179
1919-3	5	A	A	3-4	4-5	35,000	34,800-35,400	190
125	5	A-B	A-B	6-8	6-8	30,000	29,500-30,000	172
33	5	A-B	B	6-7	8	30,000	30,000-30,000	186
121	5	A-B	A-B	5-7	6-7	29,000	28,500-30,000	172
93	5	A-B	A-B	4-7	5-8	30,000	29,500-30,500	175
912	4	A	A	5	6	35,250	34,500-35,600	192
412	4	A	A	5	5	32,575	31,600-34,100	181
122	4	A	A-B	5	5-7	30,000	29,000-30,000	177
313	4	A	A	4-5	5	29,925	28,300-32,400	169
40	2	A-B	B	5-7	8	26,000	25,000-27,000	176
39	2	A-B	B	5-7	8	24,500	24,000-26,000	161

Table 15

CORRELATION OF STRUCTURAL CLASSIFICATION WITH TRANSVERSE STRENGTH

*Analysis Range: 3.30-3.45 Percent Total Carbon,
1.85-2.25 Percent Silicon*

Specimen No.	Cell Size	Graphite Type Edge Center	Graphite Size Edge Center	Average Transverse Strength, lb.	Transverse Strength Range, lb.	Brinell Hardness		
91	6	A	A	6	4-5	2615	2570-2640	187
120	6	B	A-B	7	5-7	2470	2420-2530	170
O13	5	A	A	6	5-6	2660	2560-2740	193
813	5	A	A	6	5	2508	2405-2580	186
90	5	A	A	5-6	5	2585	2560-2630	176
175	5	A	A	5-6	4-5	2590	2480-2700	168
1919-2	5	A	A	5	4-5	2700	2690-2780	190
118	5	A	A	5	4-5	2465	2370-2560	173
125	5	A-B	A-B	6-8	6-8	2380	2340-2410	172
213	5	A-B	A	6-7	4-5	2402	2250-2420	179
121	5	A-B	A-B	6-7	5-7	2190	2140-2250	172
93	5	A-B	A-B	5-8	4-7	2415	2340-2440	175
33	5	B	A-B	8	6-7	2200	2180-2260	186
912	4	A	A	6	5	2660	2560-2760	192
412	4	A	A	5	5	2307	2280-2350	181
313	4	A	A	5	4-5	2308	2280-2340	169
122	4	A-B	A	5-7	5	2240	2210-2260	177
40	2	B	A-B	5-7	8	2150	2090-2200	176
39	2	B	A-B	5-7	8	1980	1930-2030	161

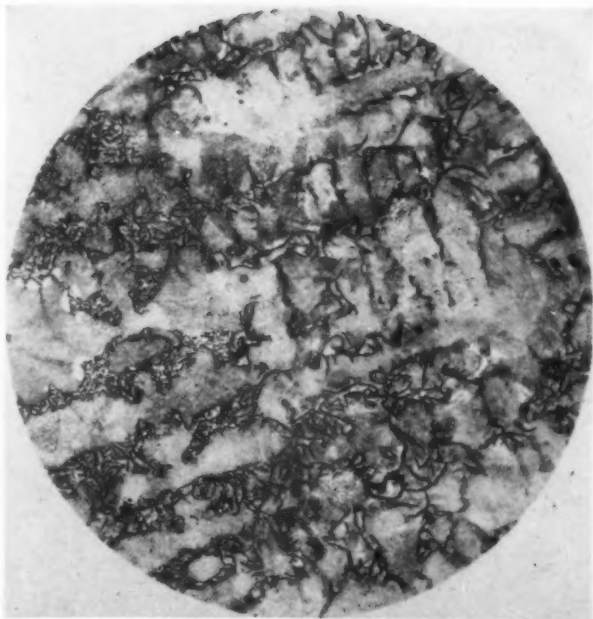


FIG. 14—SPECIMEN No. 188—CELL SIZE No. 6; GRAPHITE, TYPE A-B, SIZE 6-7; TENSILE STRENGTH, 35,500 LB. PER SQ. IN. MAGNIFICATION, $\times 100$.

the character of the matrix and very little upon the cell size or the graphite. The values for Brinell hardness, as shown in the tables, do not indicate any correlation between hardness and structure.

Strength vs. Graphite Size

25. The effect of graphite structure on the strength of cast iron is illustrated by Figs. 13 and 14. Both specimens have a cell size of 6, but they differ in their graphite characteristics. Specimen No. 5252-2, shown in Fig. 13, has Type *A* graphite of about Size No. 6; this iron has a tensile strength of 54,000 lb. per sq. in. Fig. 14 shows an iron of approximately the same chemical composition, Specimen No. 188, but containing both Type *A* and Type *B* graphite of Size 6 to 7. This latter iron has a strength of only 35,500 lb. per sq. in.

Strength vs. Cell Size

26. The effect of cell size is indicated by Figs. 15 and 16. Both specimens are of about the same chemical composition and have Type *A* graphite of Size 5. Specimen No. 222, Fig. 15, has a

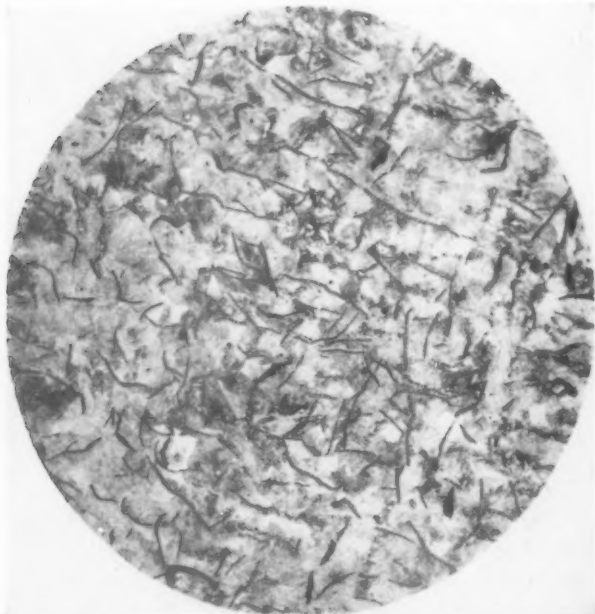


FIG. 15—SPECIMEN No. 222—CELL SIZE No. 6; GRAPHITE, TYPE A, SIZE 5; TENSILE STRENGTH, 52,500 LB. PER SQ. IN. MAGNIFICATION, $\times 100$.

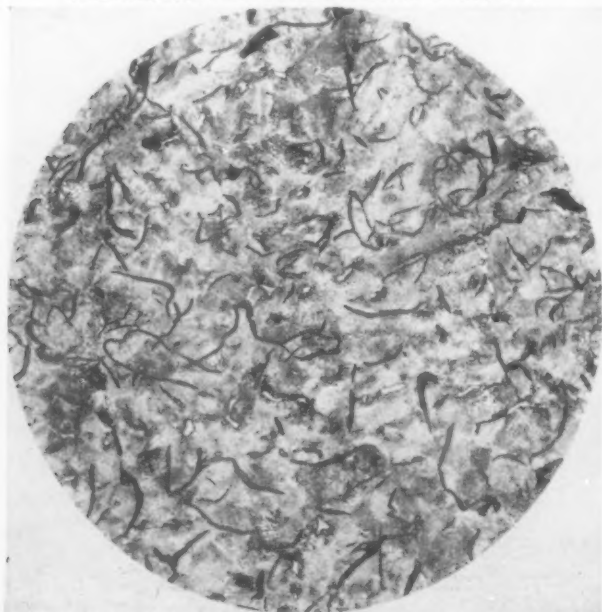


FIG. 16—SPECIMEN No. 209—CELL SIZE No. 3; GRAPHITE, TYPE A, SIZE 5; TENSILE STRENGTH, 37,500 LB. PER SQ. IN. MAGNIFICATION, $\times 100$.

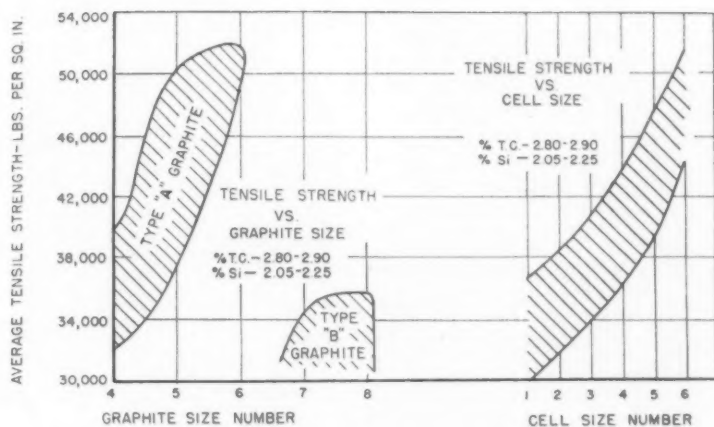


FIG. 17—GENERAL RELATION BETWEEN TENSILE STRENGTH AND STRUCTURE OF IRONS IN TABLE 1.

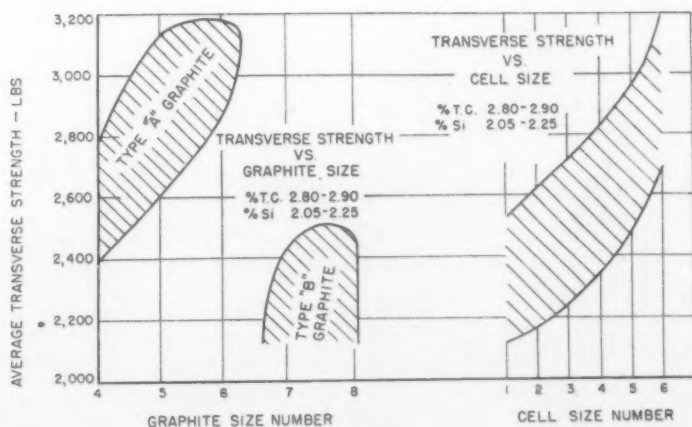


FIG. 18—GENERAL RELATION BETWEEN TRANSVERSE STRENGTH AND STRUCTURE OF IRONS IN TABLE 1.

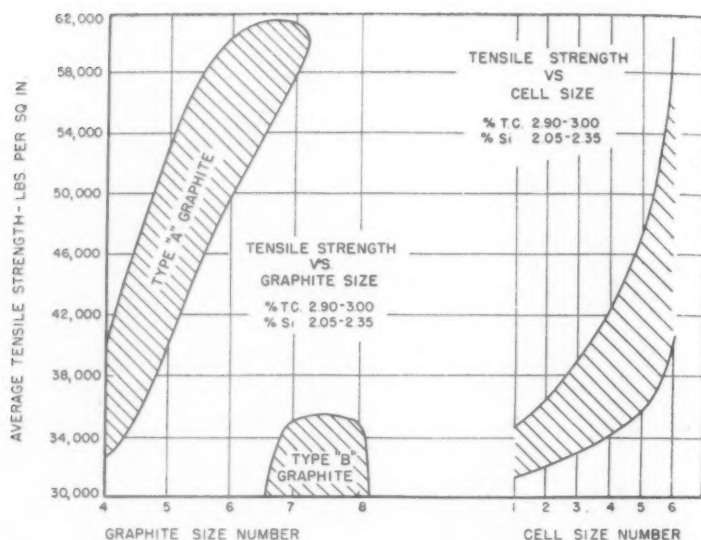


FIG. 19—GENERAL RELATION BETWEEN TENSILE STRENGTH AND STRUCTURE OF IRONS IN TABLE 2.

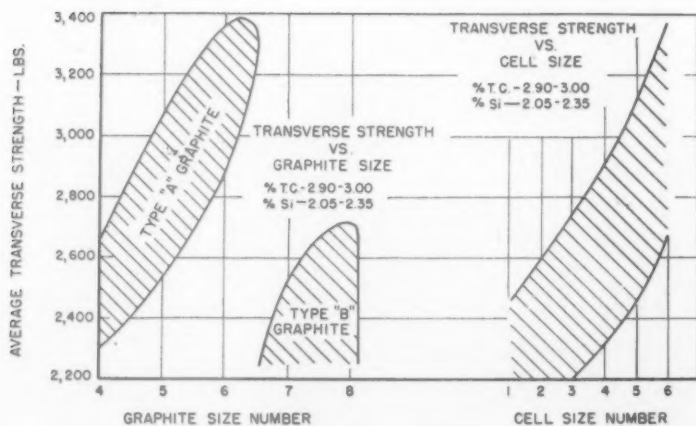


FIG. 20—GENERAL RELATION BETWEEN TRANSVERSE STRENGTH AND STRUCTURE OF IRONS IN TABLE 2.

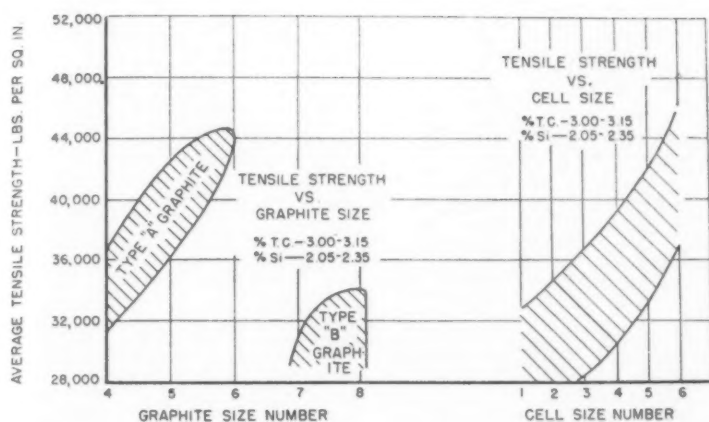


FIG. 21—GENERAL RELATION BETWEEN TENSILE STRENGTH AND STRUCTURE OF IRONS IN TABLE 3.

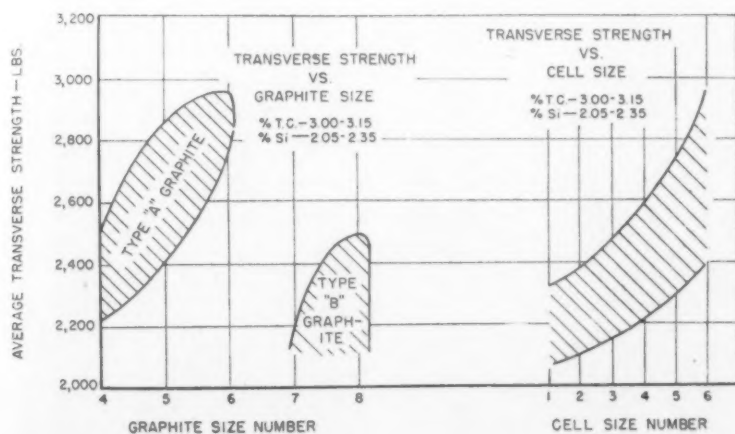


FIG. 22—GENERAL RELATION BETWEEN TRANSVERSE STRENGTH AND STRUCTURE OF IRONS IN TABLE 3.

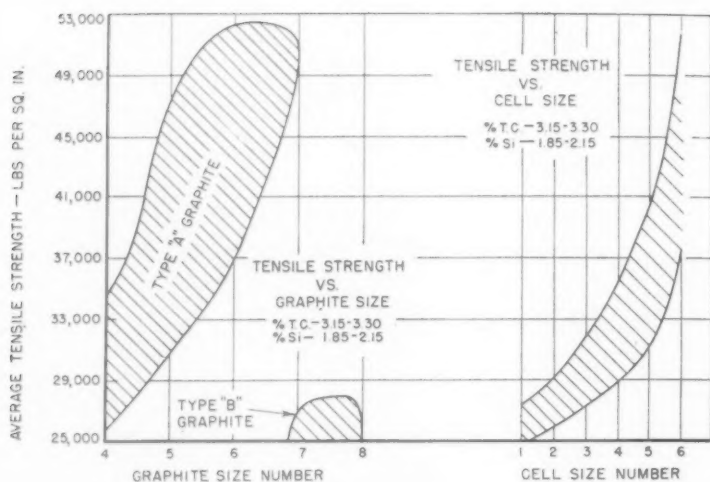


FIG. 23—GENERAL RELATION BETWEEN TENSILE STRENGTH AND STRUCTURE OF IRONS IN TABLE 4.

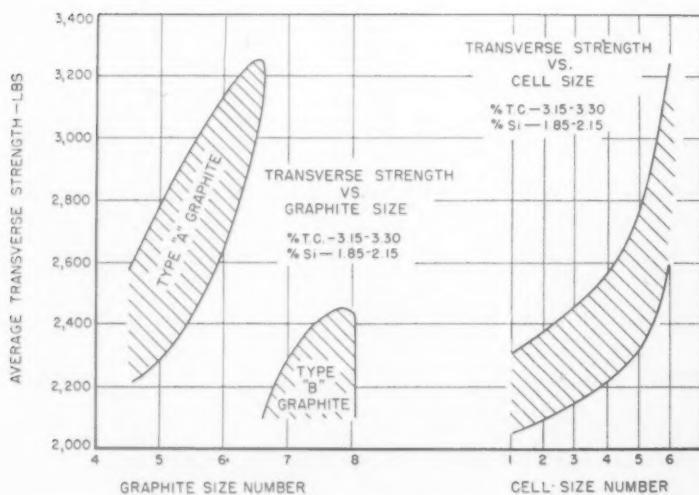


FIG. 24—GENERAL RELATION BETWEEN TRANSVERSE STRENGTH AND STRUCTURE OF IRONS IN TABLE 4.

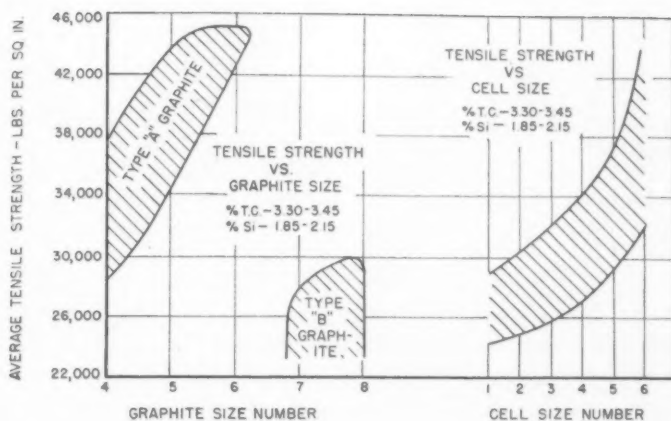


FIG. 25—GENERAL RELATION BETWEEN TENSILE STRENGTH AND STRUCTURE OF IRONS IN TABLE 5.

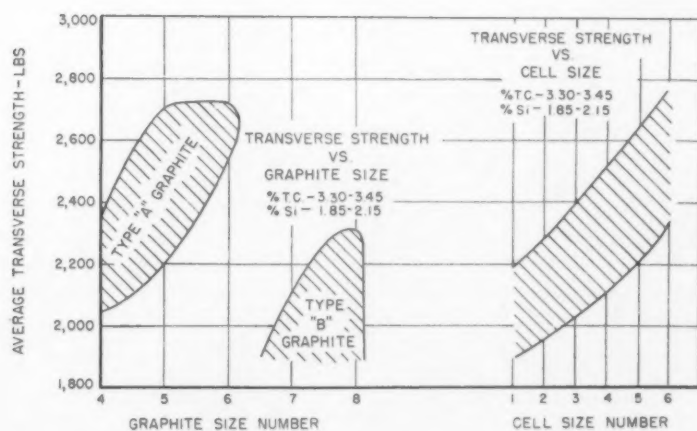


FIG. 26—GENERAL RELATION BETWEEN TRANSVERSE STRENGTH AND STRUCTURE OF IRONS IN TABLE 5.

cell size of 6 and a tensile strength of 52,500 lb. per sq. in. Specimen No. 209, Fig. 16, has a cell size of 3 and a strength of only 37,500 lb. per sq. in. The cell structure of this latter iron is shown in Fig. 12.

General Relationships Between Strength and Structure

27. The general relationship between strength and structure is shown in Figs. 17 to 26. While these curves are of an idealized nature, they show the normal variation in properties found in the irons investigated.

CONCLUSIONS

28. Since the complexity of cast iron requires statistical analysis, definite quantitative conclusions cannot be drawn. However, the data presented indicate that a correlation does exist between strength and structure. While these data are all taken from standard test bars, knowledge of the strengths to be expected from a wide variety of structures should make it possible to estimate the strength of a given section of a casting by an examination of the structure of that section.

29. This paper represents only the beginning of the compilation of the required data. It is hoped that its presentation will indicate the possibilities of cast iron classification and stimulate interest in the subject among other investigators. The effect of alloying additions and the effect of structure on other properties, such as wear resistance, are subjects which might well be considered.

30. The cast irons classified in this paper were produced under various conditions; some were produced in commercial cupolas, some in commercial electric furnaces, some in an experimental cupola, and the rest in experimental electric furnaces. The chemical analyses and the mechanical tests were made by Battelle Memorial Institute. The values reported for the mechanical properties are, in most cases, the average of two or of four determinations.

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DISCUSSION

Presiding: S. C. MASSARI, Association of Manufacturers of Chilled Car Wheels, Chicago, Ill.

Co-Chairman: R. G. MCELWEE, Vanadium Corp. of America, Detroit, Mich.

T. E. BARLOW¹ and R. G. MCELWEE¹ (*written discussion*): The author is most certainly to be congratulated on the excellent presentation of the data in this paper. Correlation of the data and microscopic examination of so many irons must have been a stupendous undertaking. In view of so many data, and since the subject is so important, perhaps we would be justified in an attempt to observe trends which may throw additional light on one of the most controversial subjects in cast iron metallurgy.

First, however, we would like to ask the author how many of the irons shown were made in a commercial furnace. We believe that this is important for a number of reasons. In the first place, the irons included in this paper seem to be predominantly low in physical properties for the chemical analyses involved. In the second place, the percentage of the irons containing eutectiform graphite is higher than would be expected. This is particularly true in the higher carbon ranges. For example, of the irons containing 3.25 to 3.40 per cent total carbon, 46 per cent were modified. This does not concur with the findings of some previous investigators who have claimed that these structures are most predominant in low carbon irons, and are relatively rare in higher carbon commercial irons.

However, commercial or not, the irons shown in this paper should show some definite trends. To find these, it was necessary to rearrange the data in many different ways. Time allowed for discussion does not permit going into these in detail, but we did find a few rather interesting facts.

The author implies, perhaps unintentionally, that cell size is of primary importance and graphite structure of secondary importance. Our own study of the data leads us to the opposite conclusion. For example, in Table 8, the strength of the strongest modified iron is 40,000 lb. per sq. in., while the normal structures show strengths as high as 61,500 lb.

¹ Vanadium Corp. of America, Detroit, Mich.

for the same chemical analyses. Or on the basis of consistency of results, irons of cell size No. 6 vary by 26,500 lb. per sq. in., partially modified irons showing lower strength with a variation of only 8500 lb. per sq. in., while completely modified irons are still weaker and vary by only 5000 lb. per sq. in. However, the relative importance of the three factors involved is really a minor point. The principal criterion is that there seems to be a definite relationship between the three factors. This relationship is evident from a casual examination of the tables, and even more evident if the cell size is plotted against the percentage of irons showing eutectiform graphite. Obviously, the larger the cell size, the greater the tendency toward eutectiform graphite and the finer the graphite. Size 8 graphite is only evident in the modified irons and even size 7 is rare in the normal irons. Eutectiform graphite seems to be as rare in the irons of cell size No. 6 as is normal graphite in cell size No. 2. These agree with the recent paper by Lorig and Boyles.² However, it introduces an interesting question. We know that eutectiform graphite is most predominant under conditions of rapid cooling. In fact, in slightly modified irons, it only occurs next to the chill, that is, in the zone of rapid cooling. We would further expect that the cell size, like the grain size, might be smaller in the rapid cooling zone. However, the data presented in this paper would indicate the possibility of having large cell size in the zone of rapid cooling if eutectiform graphite is present. We would like to ask the author if in an iron such as 188 or 137 in Table 8, the edge of the sample shows the same small cell size as the center. If we can definitely establish a relationship between cell size and graphite structure and particularly if we can show that large cells exist in zones of rapid cooling if eutectiform graphite occurs, we have made a definite step in understanding the mechanism of the formation of eutectiform graphite.

An attempt to establish a quantitative relationship between structure and strength confirms the author's conclusions that it cannot be done. The spread in physical properties in irons of the same reported structure is extremely discouraging. In one case, three irons of the same cell size, the same graphite structure and the same graphite size, varied by 18,500 lb. per sq. in. However, if we can eliminate the variations in structure, cell size and graphite size, then there should be a relationship between Brinell hardness and tensile strength. In fact, if the Brinell hardness depends almost entirely upon the character of the matrix, as the author states, perhaps we could set up an empirical formula, for calculating tensile strength, using cell size, structure, graphite size and Brinell hardness. This was attempted but again the spread in the ratio of tensile strength to Brinell hardness, even in irons of the same analysis, cell size, graphite structure and graphite size, was too great to permit quantitative correlation between tensile strength and reported characteristics. For example, in Table 8, the first three irons have the same reported structure and analysis but the ratio of tensile strength to Brinell hardness ranges from 204 to 252, or 25 per

² Lorig, C. H., and Boyles, A., "Notes on the Undercooling of Gray Cast Iron," *TRANSACTIONS, American Foundrymen's Association*, vol. 49, pp. 769-788 (1942).

cent. However, by listing the ratio of tensile strength to Brinell hardness for all the irons given, a relationship between this ratio and structure is observed. Using the symbols given in the paper, we find the following table can be made. Under "Structure," the number indicates cell size; the first letter indicates the graphite structure at the center; the second letter indicates the graphite structure at the edge of the specimen. For example, 5AB-B indicates cell size No. 5, both A and B graphite at the center of the bar and type B graphite at the edge of the bar.

<i>Tensile Strength/ Brinell Hardness</i>	<i>Structure</i>
200 to 260	6A-A Possibly 5A-A
190 to 200	5A-A Possibly 4A-A
180 to 190	4A-A 3A-A 6A-B
170 to 180	6AB-B 5A-B 4A-B 3A-B
160 to 170	5AB-B 4AB-B 3AB-B 2AB 2B-B
160 and below	2BB 1BB

This could be listed more simply as follows:

<i>Tensile Strength/ Brinell Hardness</i>	
210 and up	Normal graphite—cell No. 6
190 to 210	Normal graphite—small cell
180 to 190	Normal or slightly modified graphite— medium cell size
160 to 180	Modified graphite—variable cell size
160 and below	Completely modified graphite—large cell size

Although the variation in the tensile to hardness ratio is larger in irons having normal graphite and small cell size, there is a correlation between this ratio and the structure. Results in the more modified irons are much more consistent. Therefore, if the irons reported in this paper are commercial, or if the above table can be confirmed on commercial irons, we do have a definite relationship between structure and the tensile to hardness ratio. Although this relationship does not permit predicting the tensile strength from a microscopic examination, it does have an important commercial application. It permits the foundryman to obtain a definite idea of the structure of his iron merely by dividing the tensile strength by the Brinell hardness. Since most foundrymen have rather limited microscopic facilities, such a method of roughly determining structure should be of great value.

MR. ADAMS: I cannot give the exact figures on the proportion of irons made in a commercial furnace. However, I believe that at least 90 per cent of the irons reported in this paper were produced in an experimental induction furnace. But, at the same time, I would like to point out that, for the purpose of this preliminary work, I do not believe the source of the irons makes a great deal of difference. Admittedly, modification is much more prevalent in induction furnace irons; modified

high-carbon cupola irons are quite unusual. However, what we are trying to do here is to establish the relationship between the mechanical properties of a particular iron and its structure. We are not concerned with how that structure was produced.

My implication that cell size is more important than graphite size was, indeed, unintentional. In tabulating the results, cell size was considered first merely as a matter of convenience.

Mr. Barlow and Mr. McElwee have raised an interesting point in the matter of cell size. It would be quite in order to expect a larger cell size at the edge of a bar; however, this was not the case. As a matter of fact, the cell size across the diameter of a 1.2-in. test bar is quite uniform. There is a narrow band at the extreme edge of the bar where the cell size tends to be different from that in the rest of the bar. However, the cell size at the edge is smaller rather than larger.

The results showing the correlation between the tensile to hardness ratio and the structure are particularly interesting. It is possible that this idea can be enlarged upon when more data are available.

G. F. COMSTOCK³ (*written discussion*): The large quantity of data tabulated in this very interesting paper furnishes strong support for the author's contention that the cell size is one of the most important factors influencing the strength of cast iron. This point undoubtedly has not been properly appreciated in the past and the author deserves much credit for presenting these results, derived from such a large amount of work, to this Association.

In view of the writer's connection with the recent effort of joint A.S.T.M. and A.F.A. committees to develop a standard method of classifying graphite flake sizes and types in cast iron, he finds it quite disappointing that the author, so soon after the publication of that method, has rejected it, at least in regard to the type classification, and proceeded with his work on a different basis. Had the author been willing merely to designate his so-called "type B" as type D in conformity with the proposed standard, his paper would have lost nothing in usefulness and value, and there would have been a considerable gain in co-operation and avoidance of confusion.

It is not at all clear to the writer why "for purposes of correlation" (quoting from page 1067), the standard types B and E were combined, in this paper, with type A. It would have been very nearly as easy to separate them when the samples were classified, whether the correlation of the strength with the graphite size would have been improved, or not, by such a separation of types. As it is, the doubt exists that the author may have missed something important by including the standard types B and E in what he has chosen to call type A. His argument that in origin these types are similar does not seem especially pertinent to a discussion of strength, but it would have been very appropriate to furnish evidence as to whether or not the strength was affected by the presence of type E or type B (standard, not Adams') graphite instead of the standard type A.

³ Titanium Alloy Manufacturing Co., Niagara Falls, N. Y.

It would be very helpful to the reader if the cell size were given for Figs. 10, 11 and 12. Figure 14 is an excellent illustration of the confusion resulting from the author's use of his own special type classification instead of the proposed standard. According to that standard, Fig. 14 seems to show types D and E, whereas Fig. 13 shows type A. The lower strength of Fig. 14, therefore, may be due to the change from A to E and not entirely to the presence of type D.

On page 1090 of the paper, Fig. 16 is said to have a cell size of 3 as shown in Fig. 12. It seems as if some correction is needed here, for Fig. 12 shows type D graphite and apparently is an entirely different iron from Fig. 16. If Fig. 16 is included in the paper to show, by comparison with Fig. 15, how misleading in regard to strength an ordinary photomicrograph can be, it no doubt serves its purpose well, but it certainly does not support the statement in paragraph one that a good guess at the strength can be made after looking at the microstructure. To support the author's claims along this line, a companion set of photomicrographs illustrating the cell sizes is badly needed. Unless the cell size is difficult to determine and illustrate, one wonders why it is not shown for these important examples, and also why an illustration similar to Fig. 9 is not given in the form of photomicrographs, as was done for graphite sizes in Figs. 4 to 8, duplicating rather unnecessarily the size standards already published (reference No. 4). On account of these striking omissions, the impression that this new method of metallographic examination may after all not be very practical is hard to avoid. If the author could more effectively counteract that impression, his very interesting paper might be more useful to future investigators of cast iron.

A. J. SMITH¹ (*written discussion*): The author has contributed a good deal of interesting data on the characteristics of cast iron. However, it does not seem that he is getting all of the meat out of the problem. The argument was laid down in the introductory paragraph that the novice and, even better, the expert, can make a fair estimate of the properties of an iron by examining its microstructure, revealed in the usual fashion, and the author proposes to perform experimentation which will assist in making more precise correlation of these observations. He then shows that the degree of such correlation, even at best, is not high and introduces another structural characteristic supposedly not hitherto considered, to which he believes most weight should be given in such correlative work. That he may be right, time and further work will tell. For the present, however, the paper beclouds rather than clarifies the issue.

That cell structure is a factor in the analysis of physical properties of cast iron is not a new concept. It is usually apparent in fractures and plays an important part in fracture evaluation, which evaluation may be much more revealing than evaluation of the microstructure.

The author has made certain rather loose statements, one of which may be touched on here, "all graphite is interdendritic." To say that cast iron freezes dendritically might come closer to the truth, since no consideration is given to which constituent is primary, that is, whether

¹ The Lunkenheimer Co., Cincinnati, O.

the iron is hypo- or hyper-eutectic. Also it would appear that little cognizance has been taken of the recent excellent papers on graphitization, the full knowledge of which must inevitably be the basis for any scientific correlation.

The author has pointed out that the "*Tentative Practice for Evaluating the Microstructure of the Graphite in Gray Iron*" is entirely descriptive. This point cannot be over-emphasized. It was a particular point of the joint A.F.A.-A.S.T.M. committee that the classification should in no sense be used for correlative purposes, realizing the dangers involved therein. It was realized that the forms described represented transitions within the two general freezing processes but then irons also represent transitions within the processes, and physical properties within such transitory forms can vary tremendously. It would, therefore, seem wiser to adhere to the recommended practice, at least with our present state of knowledge, since it at least tells us the stage of the transition.

The conclusion that it should be possible to estimate the strength of commercial castings from comparison with the structure reported here is unjustified from the data presented. The author has stated that his results are entirely based on test bars. To suggest that the analysis should be applicable to commercial castings calls for supporting evidence. The growth of freezing metal from a cylindrical surface results in quite a different structure than growth from a plane surface, even though the freezing mechanism is the same. This would be especially true in heavy sections, the only sections from which a sample could reasonably be trepanned.

The question of trepanned samples is an old bugaboo before this and other specification-making bodies. Any iron foundryman is familiar with the fact that you can take samples from a given section of two like castings which will be practically identical in all respects, yet one iron will be suitable for the casting and the other highly unsuitable. This was fully recognized in arriving at the arbitration bar, which should not be looked upon as an arbitrary bar.

As to judging iron from microstructure, we recently had a case of an alloy which normally shows 30,000 lb. per sq. in. tensile strength and 3500 lb. transverse strength on a 1.2-in. bar, showing 18,000 lb. per sq. in. tensile strength and 2470 lb. per sq. in. transverse strength. Examination of a number of samples from this bar under the microscope revealed a structure perfectly normal in every respect, graphite size and distribution, and cell size which is readily apparent in this iron. While the fracture was not quite normal, it was still not significant. Only the test bar showed that this was bad iron.

MR. ADAMS (*author's closure*): There are a few points which might be brought up in connection with Mr. Comstock's discussion. In the first place, I think he is right that a certain amount of confusion might have been avoided by the use of the A.F.A.-A.S.T.M. standard classification; however, this was impractical for several reasons. In the first place, the work was started before the tentative standards were set up by the committee; therefore, their charts could not have been used. This also explains the reason for including Figs. 4 to 8 showing the size standards

used in this work. An effort was made to conform to the A.F.A.-A.S.T.M. tentative standard by changing the size designations used originally, to the corresponding A.F.A.-A.S.T.M. size number. The author's original graphite size chart was divided into 12 ranges rather than into 8.

In the first attempts to correlate strength with structure, several different types of graphite were considered. However, it soon became apparent that the strengths could be predicted satisfactorily when the number of graphite types used were limited to two. The inclusion of too many type classes made precise tabular presentation of the results practically impossible.

Eutectiform graphite was listed as type B rather than as type D in an attempt to avoid confusion, since the type A graphite, as used in this work, covers a broader field than does the type A graphite of the A.F.A.-A.S.T.M. standard. Perhaps the use of "X" and "Y" would have been a better choice for the two types used.

Mr. Comstock is correct in his impression that cell size is rather difficult to determine and to illustrate. As yet, no completely satisfactory routine method has been worked out. It is hoped that the presentation of this paper will be instrumental in getting others to work on the problem. The iron shown in Fig. 10 has a cell size of 2, Fig. 11 illustrates a cell size of 4, Fig. 12 shows a cell size of 3. Much of the structure of Fig. 11 was lost in reproduction.

Figures 12 and 16 both represent the same iron. As indicated in Table 6, specimen No. 209 has type A graphite at the center but type B graphite at the edge. The cell size photomicrograph was taken near the edge; however, as has been pointed out previously, cell size tends to be fairly uniform throughout the cross-section of a 1.2-in. transverse bar. Since the outer portion of the bar is removed in machining the tensile specimen, the structure at the center was used in comparing this property. As is often the case in grain size work in steel, it is extremely difficult to present a small photomicrograph which illustrates adequately the actual cell structure of an iron.

In reference to Fig. 14, this photomicrograph was taken in an attempt to show both the type A and the type B graphite. In nearly every case, irons containing mixed graphite types will show a narrow band of dendritic flake graphite surrounding the eutectiform area. Since these structures are intimately related, they do not need special classification for the purpose of correlation.

Mr. Smith is correct in questioning the statement that "all graphite is interdendritic." To be sure, large tonnages of hyper-eutectic cast iron, containing graphite which is not interdendritic, are made. All of the irons studied were hypo-eutectic, and that qualification should have been made.

In closing I should like to point out again that the estimation of mechanical properties by an analysis of the structure is not intended to supplant mechanical testing. Rather, it is thought that, when enough data have been collected, this method may materially aid the foundrymen in interpreting the mechanical test results.

Acid Open-Hearth Practice for Steel Castings

By C. W. BRIGGS*, CLEVELAND, OHIO, AND G. S. BALDWIN**,
BURNHAM, PA.

Abstract

The methods used in operating the open-hearth furnace by the acid practice are outlined. Lining and bottom construction, charging, melting, slag control and finishing methods are discussed. Slag analyses and furnace logs are given.

INTRODUCTION

1. There are, at this date, 116 open-hearth furnaces available for steel melting in the steel casting industry and, of this total, 70 are being operated by the acid process, producing a normal rated capacity of approximately 24,000 tons a month. This is considerably below the maximum monthly capacity, if worked on a 24-hour basis.

2. The furnaces vary in size from 10 to 125 tons rated capacity and are fired by gas or oil.

3. The acid open-hearth process is limited generally to the production of dead-killed steel and practically all acid open-hearth steel produced is used for the manufacture of steel castings or ingots for forgings.

4. It is generally considered, both in this country and in Europe, that the acid open-hearth steel-making process is one which has the possibilities of producing a high quality dead-killed steel within narrow limits of composition. The process is one which does not permit sulphur or phosphorus to be removed from the metal. The slag consists essentially of silica, iron oxide and manganese oxide. The iron oxide content of the slag is the most active oxidizing constituent; yet, as reported by Herty and Jacobs¹³, it is only approximately 1/3 to 1/2 as active, comparatively, in the acid as in the basic furnace. This feature of the process is probably the

* Technical Adviser, Steel Founders' Society of America.

** Open-Hearth Superintendent, Standard Steel Works Division, Baldwin Locomotive Works.

¹³ Superior numbers indicate reference numbers of the published articles given at the close of this paper.

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main reason that the production of high quality steel can be consistently carried out in the acid open-hearth furnace with a minimum of control features. The physical chemistry of the process is not entirely understood.

5. A study of the proceedings of the Acid Open-Hearth Conferences, held by the American Institute of Mining and Metallurgical Engineers, will show that there are material differences in the acid practice of the various foundries throughout the country. In general, it may be said that such differences are the result of local experiences and needs, yet all are ending with an acceptable steel for casting production. It is not the purpose to present here all the various modifications that may be found in the production of steel by the acid practice.

BOTTOM CONSTRUCTION

6. The main desire of most melters is to have a "sharp working" furnace. By "sharp working," the melters refer to a fast melting furnace with a plentiful supply of good fuel and gas developed by well designed burners and an efficient regenerator system. In a "sharp working" furnace, the melter has adequate control of the bath temperature. Slow working furnaces often require various modifications of melting procedures and considerable skill is required to prevent cold melting and the effects that accompany it. Adequate control of temperature is perhaps the most dominant single factor associated with the process.

7. No attempt will be made to explain or discuss open-hearth furnace design, as such matters do not necessarily constitute a part of the subject of this paper. All that is necessary is to point out that the walls and roof are lined with silica brick.

Sand Used

8. The usual procedure in making a bottom for the acid furnace is to use a good grade of silica sand and to build it up from the brick lying on the pan to a depth of from 10 to 18-in. Silica bricks are laid on the pan to a depth of 15 to 22-in. One foundry reports the use of a deep layer of silica bricks laid on the pan, but with only approximately 6-in. of sand built up on the bricks.

9. From the time the furnace has started to warm up, it takes approximately 10 days to put in a good bottom. The furnace is first dried with a wood fire for about a day and then the fuel is turned on and the burners are reversed about every half hour until the

furnace is hot. Sand is then added at intervals until a bottom of the necessary depth is obtained. The bottom is sloped in all directions toward the tap hole.

10. About 90 per cent of the acid open hearths use one grade of sand, an Ohio open-hearth silica sand. The silica content of the sand is approximately 96 per cent and usually the sand is purchased in the graded condition with about 25 per cent of the sand remaining on the 20 mesh sieve. It has been stated³ that the purpose of this grading is that, since the coarse particles are distributed throughout the sand, they enable the heat to penetrate the sand more readily, thereby allowing the entire sand layer to fuse instead of just the top fraction of the layer fusing.

11. From information available, it seems that a sand which fuses at about 2900°F. is a proper sand for bottom building. Such a sand will fuse on its top surface $\frac{1}{8}$ -in. in 5 or 6 min. Fusion will be fairly uniform throughout the added layer in half an hour if the graded type is used.

12. Two foundries report that their practice is to put in a good bottom of 10 to 12-in. in 4 to 5 days after the furnace is hot.

Fusing Procedure

13. If the furnace is kept hot, sand can be added at rather frequent intervals. In a 60-ton furnace, sand is added at the rate of 700 lb. approximately every half-hour. This rate is not kept up for the 4 to 5 days as there are other things that require attention which are time-consuming, such as making the tap hole, fixing ports, etc. A 60-ton furnace will require approximately 55,000 lb. of sand, for a good bottom. The bottom sands are added by shoveling.

14. Bottom building by making small frequent additions of sand also is an acceptable practice. A hard, well-sintered bottom can be put down in this manner at the rate of approximately 1000 lb. of sand per hour. A bottom 14 to 16-in. deep built in 80 hrs. for a 70-ton stationary furnace used a total of 85,000 lb. of sand.

15. An acceptable bottom can be put in a 25-ton furnace with 35,000 lb. of sand while a 50-ton furnace will require about 55,000 lb. and a 100-ton furnace will need approximately 95,000 lb. of sand.

16. Some foundries use a mixture of fine sand and acid slag in the ratios of 1 part slag to 9 parts of sand for building bottoms. Others have found it expedient to add a small percentage of fire

clay or to make additions of a low fusion sand to the regular grade of high fusion fine sand. These modifications are made with the purpose of reducing the fusion temperature of the bottom material so that it will fuse readily. It is believed, however, that these modifications do not produce the hard-fused bottom that is possible when a high quality bottom sand is used alone.

17. An interesting modification in building a bottom is the reported use of 40 mesh powdered 50 per cent ferrosilicon, mixed with sand in the ratio of about 1 part ferrosilicon to 100 parts of sand. The bottom prepared in this manner has stood up exceptionally well for 3 years.

18. After a bottom is completely built up, it is the practice in some foundries to add acid slag to the furnace, melt it, and splash the bottom with a good coating. This is done so that the slag will penetrate the sand and will not allow the steel melted on the first heat to penetrate easily.

19. Another foundry reports the use of quartzite blocks on the end slopes above the slag line. The blocks are approximately 4x4x10-in. and they are set with expansion joints provided. Some spalling is recorded but not sufficient to be of concern. The slopes are maintained very well and thus produce a constant throat area.

20. Some of the furnaces have insulated bottoms. In these furnaces, a combination of insulating concrete and insulating brick is used. The concrete, 3-in. thick, is placed on the flat of the pan and 2½-in. insulating brick is placed on the sides and ends of the pan to slag line height.

Construction of Tap Hole

21. There are a number of ways to construct the tap hole. One method is to put into the furnace a water-cooled tube and to build the bottom over it. If a 6-in. tap hole is wanted, a 4-in. tube is used, as the sand does not sinter all the way to the water-cooled tube. Another method is to use specially shaped tap-hole brick. Eight bricks shape the circle and two sets are required. Another method for shaping the hole is to use an electrode and build the bottom around it. The sand fuses to the electrode. After the bottom is completed the electrode is rammed out. Wet sacks are rammed into place and faced up as a substitute to the water-cooled tube method. During the building of the bottom, it is necessary to open up the tap hole and reload it with another set of wet sacks.

22. The most commonly used method of tap hole construction

is to make a wooden plug the size of the hole desired. The plug is covered with a refractory material. By the time the plug is burned out the tap hole is constructed.

23. Tap holes are generally plugged with coal or with a mixture of buckwheat, coal and sand or coke breeze and sand. The coke or coal content will vary from 50 to 70 per cent of the mix depending on the desired hardness of the tap plug. The mixture is backed up on both the outside and inside with molding sand.

Bottom Replacement

24. Some steels, such as the low carbon steels, are quite hard on furnace bottoms and hence bottom replacement will depend on the type of steel made as well as the construction of the furnace. A steel maker who produces nothing lower than 0.50 per cent carbon steel may make a bottom last 3 to 5 years. Furnace bottoms are renewed in most steel foundries every campaign or every other campaign; this means after every 1000 to 1500 heats. One foundry reports that the bottom is renewed on a 10-ton furnace every campaign, which includes from 1700 to 2000 heats.

25. The hearth sand consumption per ton of steel produced will vary, depending on the type of steel made and the construction of the bottom. Values from 50 to 125 lb. per ton have been recorded. Most of the sand that is added between heats is placed just below the slag line to take care of high oxide slags. The foundry reporting the highest figure has found that the use of a very pure silica sand, 99.5 per cent, has improved bottom practice when using a low silicon, low manganese charge. No attempt is made to sinter this sand in the furnace. Approximately 40 lb. per ton of charge is added immediately before starting to charge.

26. Holes in the bottom of the furnace are repaired by blowing out the slag with steam and adding sand and allowing it to sinter. A very good practice is to add a small quantity of crushed ferro-silicon to the hole, deoxidize the FeO in the slag and then add sand, puddle, and allow it to fuse.

27. It is believed that FeO is the most active compound in the deterioration of the acid bottom.

28. Compositions of the working hearth of an acid open-hearth furnace have been reported by Ferguson¹ and are shown in Table 1. Samples were taken by driving a 1½-in. diameter tube about 2-in. into a midway position in the banks, approximately 6 ft. from the tap hole of a 60-ton furnace.

Table 1

COMPOSITION OF THE WORKING HEARTH FOR A 60-TON ACID FURNACE¹

Oxide, per cent	Composition, Per Cent			
	70.54	69.24	67.40	73.60
SiO ₂	70.54	69.24	67.40	73.60
FeO	15.84	18.00	20.40	17.50
Fe ₂ O ₃	5.51	4.44	3.96	3.44
Al ₂ O ₃	2.29	2.65	1.06	2.06
MnO	5.28	4.05	5.02	2.27
CaO	0.08	1.04	2.10	0.84
MgO	0.72	0.86	0.44	0.21
	100.26	100.28	100.38	99.92
Bottom in Service	12 Weeks	13 Weeks	8 Years	8 Years

29. These figures possibly may not mean much but they do show that an iron oxide network, which is presumably required to cement the silica crystals, gradually corrodes and ultimately fluxes away the silica grains, thus requiring constant renewal of the working face.

THE CHARGE

30. The acid open-hearth charge usually will consist of pig iron, foundry scrap (gates and risers) and purchased scrap.

Scrap

31. The purchased scrap should be of the solid type and as free as possible from hydrated rust. Wet rust is regarded as a source of hydrogen content in the steel and, therefore, must be kept out as much as possible. Under the present conditions of the war emergency, most any and all scrap is being used which includes very light sheet scrap, automobile graveyard scrap, and detinned tin cans. Considerable of this scrap is quite heavily covered with rust. The scrap should have a low content of sulphur and phosphorus, if possible below 0.04 per cent each, since neither of these elements can be eliminated in the acid process.

32. Since the phosphorus and the sulphur content are increasing in the scrap being prepared for acid charging, all that can be done is to resort to careful chemical check on scrap coming in and use as much as can be used and still stay just below the finishing phosphorus and sulphur specification requirements.

Pig Iron

33. The pig iron content of the charge will vary from 10 to 50 per cent. The average charge should contain approximately 15 to 20 per cent pig iron.

34. The percentage of pig iron is figured on the basis of the carbon content of the charge and its relation to the finishing carbon. Some foundries plan on having the total carbon content of the charge greater than the finishing carbon by about 0.50 per cent while others believe that a better figure is 0.70 per cent. In some cases, even higher values are desired.

35. Pig iron is added to produce sufficient carbon in the heat at melt-down so that a vigorous boil will result on the addition of iron ore.

36. It is possible to add carbonaceous material to bring up the carbon content of the charge. The procedure is becoming increasingly important these days because of the lack of high carbon scrap. Some operators prefer the pig iron addition in preference to carbonaceous material, especially those who desire a high manganese content in the charge. Under normal conditions, it is possible to attain this condition by the use of pig iron that contains rather high manganese contents.

37. In the past, most low phosphorus pig iron as used in the acid open hearth would average about 1.25 per cent manganese but today, because of the war emergency, very little pig iron is produced containing over 1.00 per cent manganese.

38. It is the usual procedure for foundries to purchase pig iron with a 1.00 per cent maximum manganese content and approximately 85 per cent of all acid open-hearth foundries use this type of pig iron.

39. A few foundries like a high manganese residual and purchase pig iron, when they can get it, to specifications calling for 1.50 to 2.00 per cent manganese.

40. Phosphorus and sulphur specifications of pig iron are usually set at 0.035 per cent each and pig iron purchased under these specifications will record 0.025 to 0.029 per cent phosphorus and 0.025 to 0.028 per cent sulphur. The silicon content will usually be 1.50 to 1.75 per cent.

Silicon and Manganese Content

41. The average silicon and manganese content of the charge has a considerable influence on the subsequent bath characteristics

and operations.

42. The silicon content of the charge will usually be about 0.60 to 1.00 per cent. In some gas-fired furnaces, silicons as low as 0.40 per cent in the charge have been reported. These values are believed necessary to prevent over-oxidation of the bath and reduces to a minimum the attack on the silicious banks and bottom by the metallic oxides formed during melting. The actual content of silicon figured for the charge will depend on the silicon content obtained at the time the charge is completely melted.

43. The manganese content of the charge varies over wide limits of from 0.4 to 1.75 per cent. A number of foundries desire to have the higher values of 1.25 to 1.75 per cent. This often requires large amounts of pig iron or the addition of ferromanganese or spiegel. Most foundries plan on having approximately 0.75 to 1.00 per cent manganese in the charge.

44. The carbon content of the charge will also vary somewhat. If the finishing carbon is to be 0.30 per cent, then the charge should contain about 1.00 per cent carbon.

Methods of Charging

45. There are two methods of charging furnaces, one called unit charging and the other level charging. In unit charging, the entire charge is placed in the furnace at one time. In defense of this method, it is pointed out that intermittent heating and cooling of the furnace is not particularly desirable for any furnace and that by charging the heat in various parts, the slag line is cut at different heights. Also, sometimes the second and third charges are put in at too early a stage, before the furnace is hot enough. This condition will give an unsatisfactory melt-down.

46. Other operators believe that "level charging," or charging the heat in two or three parts, is essential for quick melting, rapid slag formation and the avoidance of sulphur pickup and that it reduces oxidation. There is ample room above the charge to burn the oil in the level charging method.

47. Since both methods are used, it appears that a unit charge will melt faster in a slow-working furnace, whereas the charges melt faster in a "sharp working" furnace if level charging is used.

48. There are a number of practices in regard to the position of the pig iron in the charge. One method is to put all the pig iron on the bottom of the charge. The purpose of this is that the pig iron will prevent the oxides of the scrap from damaging the hearth dur-

ing the melting. In other cases, the pig iron is spread uniformly on top of the charge with the idea of protecting the furnace banks and ends in this way.

49. Two foundries report that the pig iron is placed above a layer of light open scrap, such as springs or turnings, so that the heat will get down and circulate throughout the bottom of the charge.

50. The pig iron may be added as a second part of a leveling charge or it may be added to the bottom, middle and top of a unit charge. It has been stated that it does not matter where it is placed, as it melts first and runs down and protects the bottom. The authors do not concur with this thought and believe that the majority percentage of the pig iron should be on the bottom of the charge. It is suggested that the pig iron on the bottom should not exceed 12 per cent of the charge.

51. The charging time for a furnace will depend on the character of the scrap and the amount of the charge (size of the furnace). For example, a 145,000 lb. heat can be charged in approximately $2\frac{1}{2}$ hrs. total charging time by a charging machine. The charge was added in two parts. The temperature of the charge averages about $2,300^{\circ}\text{F}$. when the second part is added.

THE MELT

52. As soon as the furnace has been charged, the fuel, which was partly turned off during charging, is placed on full operation and the flame is reversed about every 15 to 20 min. The flame, during the melting period, is a sharp, oxidizing flame adjusted so as not to obtain too much of a carbon drop. The time required to melt a 145,000 lb. heat after charging is complete is about 3 hours. A 22,000 lb. charge can be melted in approximately an hour in a 10-ton furnace.

Functions of Silicon and Manganese

53. The function of the silicon in the charge is to protect the carbon from oxidizing too rapidly during melting, as well as to prevent erosion of the banks. The manganese in the charge aids in obtaining a comparatively clean bath at melt-down.

54. At the time the bath is completely melted, the carbon content for casting heats generally is from 0.20 to 0.30 per cent above the finishing carbon content. Thus, for a 0.30 per cent carbon steel the carbon content at melt-down will be about 0.50 to 0.60

per cent. During the oxidation period, this carbon will be reduced to a value of about 0.15 to 0.20 per cent and the finishing additions will bring the finishing carbon back to the 0.30 per cent figure. The carbon content at the melt-down should be high enough so that an extensive vigorous boil will be obtained.

55. The silicon content at the melt-down should not be over 0.20 per cent. If the silicon content is much above this figure, considerable time will be lost in oxidizing the silicon and the boil will not be vigorous until the silicon content has dropped to below the 0.20 per cent value. If the silicon content is too low, the carbon content at melt-down must be higher than the suggested 0.30 per cent above the finishing carbon as the rate of carbon drop will be too fast. A carbon drop at the rate of 60 points per hour is about the limit.

56. For best results, it is believed that the silicon content at melt-down should be about 0.15 per cent.

57. The silicon content of the bath at the time of melt-down varies directly according to conditions of the charge in the following order of probable importance:

- (1) Silicon content of the charge.
- (2) Working speed or sharpness of the furnace.
- (3) Compactness of the charge.
- (4) Manganese content of the charge.

The manganese content of the bath at the time of melt-down also varies directly in the following probable order:

- (1) Manganese content of the charge.
- (2) Silicon content of the charge.
- (3) Sharpness of the furnace.
- (4) Compactness of the charge.

With these points in mind the manganese content will vary as follows:

<i>Manganese Content of Charge, per cent</i>	<i>Manganese Content at Melt-down, per cent</i>
1.25-1.75	0.30 to 0.40
0.60-1.00	0.15 to 0.20

58. From the above, it may be seen that the amount of silicon in the charge has more influence on the amount of manganese present at melt-down than the manganese has on the silicon content.

59. The compactness of the charge is an important determining factor on the silicon and manganese contents at melt-down due to the fact that the smaller the surface area per lb. of charge, the smaller will be the proportion of iron oxide formed during the melting. This point should be considered carefully, especially when changing from scrap consisting largely of crops, wheels, couplers, knuckles and the like, to light scrap composed of turnings, auto body stock and frames, sheet punchings and whatever else is available during these war times.

60. The manganese and silicon contents at melt-down also will depend considerably upon the type of furnace and the fuel and atomizing method used. Sharp working furnaces, and those which permit heats to be shaped up quickly, can use lower carbon, manganese and silicon contents at melt-down. There has been considerable discussion over the advantages to be derived by using a high manganese content in the charge and at melt-down. Certain acid open-hearth operators have stated that a heat will work more satisfactorily when it melts with a manganese content at 0.30 to 0.40 per cent than at 0.15 to 0.20 per cent. More fluid-working slags are produced with a lower FeO content. It has also been stated that cleaner steel is obtained with better mechanical properties. It also permits closer control of the carbon drop during the working and finishing of the heat.

61. The high manganese content of the charge permits a MnO content of 25 to 30 per cent in the slag. The MnO is largely in a state of combination with silica², which allows some of the iron oxide to be freed from its combination with silica. The released FeO diffuses into the metal. Under these conditions, the iron oxide of the slag would be about 12 to 15 per cent. With iron oxide at 12 per cent, without the high MnO content, the slag will be very thick, heavy and gummy. With the high MnO content the slag will be thin, but not watery, if the FeO content is only 12 per cent. Additions will go through the slag easily, the heat works faster and picks up temperature faster.

62. It has been stated⁴ that, with the high manganese charge, less erosion of the furnace lining is obtained. Furthermore, there is present more manganese to combine with sulphur to form manganese sulphide inclusions, which are less harmful than the iron sulphide type.

63. The use of the high manganese in the charge requires the use of more iron ore to bring the carbon down to 0.15 to 0.20 per

cent than is required when the charge contains manganese between 0.75 to 1.00 per cent.

Table 2

TYPICAL COMPOSITIONS OF THE SLAG AT MELT-DOWN

<i>Charge Type</i>	<i>SiO₂</i>	<i>FeO</i>	<i>MnO</i>
Low Manganese	50	35	10
High Manganese	50	20	25

THE OXIDATION PERIOD

64. A good, vigorous boil is desired by all casting producers using the acid open-hearth process. A long, vigorous boil is obtained by the addition of iron ore to the bath to bring about the oxidation of carbon in the melt, producing CO. The bubbles of CO gas rising out of the bath give the boiling action appearance.

65. As the oxidation of carbon to carbon monoxide is endothermic, a high temperature is required before a vigorous boil develops. Studies made by the use of the carbon-silicon carbide thermocouple³ showed that a temperature of 2750°F. should be reached before the addition of ore to obtain the proper boil.

66. It is the practice in most foundries to add the iron ore to the bath almost as soon as the bath is melted and not wait until the bath reaches a certain minimum temperature. This practice has largely resulted from using charges that are very similar in character day after day so that the amount of iron ore needed is pretty well stabilized. It must be remembered, however, that present-day charges may change in character rather frequently so that set rule-of-thumb practices may not be sufficient to produce quality steel. The loss in carbon is light until the proper temperature is obtained for the vigorous boil to begin.

67. The use of large quantities of iron ore causes a very fast carbon drop at first with the result that there is a greater absorption of heat due to the oxidation of the carbon. The boil then falls off in vigor because of insufficient heat in the bath. The slag thins out because of the higher FeO content and attacks the hearth. If the ore additions are too light, the speed of reactions is unduly slowed down, the FeO content of the slag is lowered, and the slag becomes thick and viscous.

68. The boil should be vigorous during the first part of the oxidizing period and should taper off during the latter part with

the rate of carbon drop of the initial period being probably twice as great as at the end. Such conditions permit a better grade of steel.

Rate of Carbon Drop

69. The rate of carbon drop will vary somewhat depending on the construction of the bath. In shallow baths, a rate of carbon drop of from 0.40 to 0.55 per cent per hour in the initial hour may be attained. It is believed that the rate of carbon drop at tapping is generally in the neighborhood of 0.12 to 0.20 per cent per hour. This rate at which the carbon drops is not of too much importance from the standpoint of producing quality steel. More important is the obtaining of the desired slag condition, the proper temperatures and low silicon residual.

70. It is the opinion of the authors that a vigorous boil during the early stages after melt-down is necessary for the elimination of gases and inclusions and is a requisite for the production of quality steel, and that any carbon drop which will give these conditions is sufficient, regardless of the rate of drop. It is furthermore believed that an active bath should be maintained at all times to prevent the building up of gases.

71. Some foundries have a rule of not permitting further additions of iron ore after one hour prior to the blocking of the heat. If further carbon drop is necessary it is obtained by the use of lime. These steps are taken to permit the FeO content of the slag to drop. There is less chance of obtaining dirty steel if rules similar to this are followed.

REFINING

72. Refining is generally understood to mean:

- (1) The cessation of ore feeding.
- (2) The slowing-down of the reactions of the process.
- (3) The final steps in obtaining a proper slag.

73. The silicon and manganese residuals present after the boil will vary somewhat depending on the amount of manganese present in the charge and the type of boil obtained. The silicon content will be usually from 0.05 to 0.10 per cent. Most melters believe that the residual silicon should be about 0.06 per cent though the value of 0.10 is not considered poor practice, when the manganese residual is high.

74. The American practice requires that some time during the heat the silicon residual of the bath should be less than 0.07 per cent for the purpose of making certain that any gases picked up during the melting period are eliminated. The residual manganese will be about as follows:

<i>Manganese in the Charge,</i> per cent	<i>Residual Manganese,</i> per cent
0.60 to 1.00	0.06 to 0.10
1.25 to 1.75	0.12 to 0.20

75. In most foundries, the practice is to take frequent test samples for carbon analyses and when the carbon reaches the desired figure the heat is blocked and tapped. This practice can easily be adhered to with the use of rapid carbon analyzers.

76. In a few foundries, it is the practice to let the carbon content of the bath drop down to 0.10 to 0.15 per cent. The carbon content is then brought back to the finishing carbon by the addition of recarburizers as well as the deoxidizers. The rate of carbon drop slows up considerably in the neighborhood of 0.10 especially if the amount of iron oxide in the slag has been reduced as the heat proceeds, which is the usual procedure. Carbon tests can be more accurately read by melters' eyes at the lower carbon contents. There is an advantage in this if the foundry does not have a rapid carbon analyzing instrument.

Lime Additions

77. During the period of the carbon drop, it is the practice of some foundries to add a small percentage of lime or limestone to the slag. This is done to increase the fluidity of the slag especially when the MnO content of the slag is low.

78. Lime additions to the slag will also aid in carbon removal, but at a slower rate than can be obtained by the same quantity of iron ore addition. The lime frees some of the iron oxide of the slag from combination with the silica and the freed iron oxide then reacts to oxidize the carbon of the bath. If, toward the finish of a heat, it is desired that the carbon elimination of the heat be a little faster, but not as fast as would be obtained by the addition of iron ore, then it is the acceptable practice to add lime.

79. Those foundries interested in studying the viscosity of slags during the heat will add lime to have a slag fluid enough to run the viscosimeter.

80. The CaO content of the slag will vary depending on the practice, but it probably will not be necessary to be greater than 10 per cent. Some finishing slags will only show 3 to 6 per cent CaO. Lime can be added at any time during the heat. Usually it is added after the iron ore has been added and the boil is active and as the slag begins to thicken. The large quantity additions are made early, such as approximately $1\frac{1}{2}$ hours before deoxidation. Small quantities of lime often are added within 30 min. of blocking to bring about a continued gentle carbon drop or for slag fluidity correction purposes.

81. Low carbon heats seldom require lime additions, since there is sufficient FeO present in the slag to maintain fluidity. Lime additions to alloy heats are made similar to that made for carbon steels.

82. It has been noted that if too much lime is added, a very watery slag is produced which is responsible for cutting the banks.

BLOCKING AND DEOXIDATION

83. There are two ways of finishing a heat, first, by stopping the carbon drop by the addition of deoxidizers to the bath, and second, by allowing the oxidation to cease by permitting time to establish equilibrium conditions. In nearly all cases, the first method is the one that constitutes the foundry practice.

84. The first method requires the use of fluid finishing slags to secure clean steel⁵. Viscous finishing slags prevent the absorption of non-metallies from the metal and cause a throwback of inclusions in the ladle.

85. Silico-manganese, spiegel or ferrosilicon and ferromanganese are used as the blocking agents and as sources of the silicon and manganese necessary to finish the heat. Such additions practically stop the further reduction of carbon by the formation of oxides. If the iron oxide content of the bath is low, the silicate inclusions in the metal need not be high.

86. The use of the first method facilitates production. In the second method the bath conditions are controlled so that with time the metal and slag reach a passive condition or equilibrium at the end of the heat. At this stage, the bath may reduce silicon from the slag. The bath condition is indicated by the cessation of the boiling action and a flat bath.

Silicon Reduction

87. It has been stated by certain European operators that the best acid open-hearth heat is produced when silicon is reduced. Foundrymen in this country believe that the second method produces a steel of considerably lower fluidity and that a silicon pick-up of more than 0.03 to 0.05 per cent is decidedly detrimental to fluidity. Increased opportunity for blowholes in the solidified steel also have been traced to the silicon pick-up process.

88. A high manganese addition to a low carbon heat will produce a silicon pick-up, but this condition is different since the heat is blocked with the manganese addition.

89. Silicon reduction from the slag is easier with high bath temperatures and with the higher carbon content baths. Silicon reduction can be prevented or kept to a low figure by increasing the draft, probably resulting in lowering the bath temperature.

90. If the FeO content of the slag is low, around 10 to 12 per cent, and the MnO content is low, it is possible to obtain a silicon reduction at the end of a heat just prior to blocking. This is not serious, provided the reduction is small and extends only over a short period.

91. A partial block, some 25 to 40 min. prior to adding the deoxidizers, has been reported by using spiegel in quantities of 0.8 to 1.5 per cent of the charge. This partial block is used in "sharp working" furnaces where the rate of carbon drop is high. Action on the bath continues after the spiegel addition but the rate of carbon drop is slow.

92. Both silico-manganese and ferromanganese and ferrosilicon additions are being used by the foundry industry in the acid open-hearth process. Reports from the foundries indicate that the use of silico-manganese does not produce any outstanding beneficial results.

93. Some slight saving in the time between making the additions and tapping is effected by the use of silico-manganese. The heat is tapped 10 to 15 min. after the silico-manganese is added. If the two are added separately as ferroalloys, it is the usual practice to add the ferrosilicon first. The ferromanganese is added about 5 to 8 min. after the ferrosilicon addition and the heat is tapped 10 to 15 min. later.

Final Additions

94. A few add the ferromanganese ahead of the ferrosilicon. The heat is tapped as soon after the addition of the ferrosilicon as

possible. The reason for this is that because of the affinity which silicon has for gases, it is disliked as a block and, for this reason, should not be present in a quiet bath any longer than the minimum time. It is for this reason that some prefer spiegel or ferromanganese additions as constituting the method of blocking the heat.

95. The recovery of manganese is often low when ferromanganese is added first. However, this is not the case if the MnO content of the slag is high before the addition of ferromanganese. Since most operators use a low MnO content slag, the ferrosilicon is added first. This permits a greater recovery of manganese from the ferromanganese addition.

96. It has been reported that, when the ferromanganese is added after the ferrosilicon, the percentage of manganese recovered is controlled by the length of time the metal remains in the furnace prior to tapping. Losses obtained under normal conditions range between 30 to 40 per cent of the amount added, if the MnO content of the slag is around 10 to 12 per cent.

97. Some ferromanganese may be added to the ladle, especially when low carbon manganese alloy steels are being made. The manganese, normal for a carbon heat, is added to the furnace and the additional manganese needed is sometimes added to the ladle. It is believed that 60 to 70 points of manganese can be added to the ladle whenever desired.

98. Aluminum is added to the ladle in quantities of 0.01 to 0.06 per cent as a deoxidizer and grain refiner. Not all acid open-hearth heats employ the addition of aluminum to the ladle. Some operators have encountered the low ductility problem in conjunction with the use of 0.01 to 0.03 per cent aluminum as reported by Sims and Dahle⁶, while others use the critical amounts of 0.02 per cent aluminum and do not obtain a reduction in the ductility of the finished steel.

99. Ferrotitanium is added to the ladle for its effect on grain size and impact properties of certain steels. It is used especially in manganese steels to give them a fine grain over a broad range of heat treating temperatures.

100. Calcium-silicon or calcium-manganese-silicon is added to the ladle as a final deoxidizer by some foundries. These deoxidizer alloys are used in connection with aluminum to produce a more desirable inclusion type, thereby promoting ductility. Additions will range from 2 to 5 lb. of the deoxidizer per ton of steel.

101. The tapping temperature of the metal will range from

2850 to 3000°F., depending on the size and character of the castings to be poured and the number of openings to be made. The temperature is judged by the aid of the film or set test. Each type of steel will form a film at various times depending on analysis and temperature. These times are correlated and goals, depending on the number of castings and type of steel, are set.

102. A log of an excellent acid open-hearth heat is given in Table 3.

Table 3
LOG OF ACID OPEN-HEARTH HEAT

Size of heat: 145,000 Lb.

Composition desired: Carbon 0.25 to 0.30 per cent—Manganese 0.75 to 0.85 per cent—Silicon 0.30 to 0.40 per cent.

		<i>Carbon, per cent</i>	<i>Slag Viscosity, in.</i>
11:00	2000 lb. sand added to banks and bottom		
11:10 to 11:40	1st part of charge added		
12:30 to 2:00	2nd part of charge added		
5:15	Melted		
5:19	1st test	0.72	6 $\frac{1}{8}$
5:25	300 lb. ore		
5:54	2nd test	0.66	4 $\frac{7}{8}$
6:15	1000 lb. ore		
6:41	3rd test	0.39	3 $\frac{1}{4}$
6:54	4th test	0.30	2 $\frac{3}{4}$
7:09	5th test	0.23	2
7:12	400 lb. limestone		
7:30	6th test	0.18	2 $\frac{1}{2}$
7:47	7th test	0.17	2 $\frac{1}{2}$
7:57	8th test	0.15	2 $\frac{1}{4}$
8:12	200 lb. burnt lime		
8:25	9th test	0.14	2 $\frac{3}{4}$
8:30	2050 lb.—80 per cent FeMn and 1160 lb.—50 per cent FeSi		
8:40	Tap		

SLAG CONTROL

103. Very little has been published concerning systematic test control methods on acid slags. However, quite a few operators have developed methods of their own that are doing a better job more easily than was done in years past when the eye of the melter was the only control medium. Three of the control methods are enumerated:

- (1) Viscosity measurements by means of the viscosimeter as used in basic shops, or a modified form of it.
- (2) Slag cake tests examined for surface appearance, soundness of test and color of fracture.
- (3) Specific gravity measurements.

104. All of these tests have their advantages and are working out in various shops. Of the three methods, the authors prefer the

viscosity test. It is a very simple test to make, is accurate for the same slag over wide ranges of variables including speed of pouring, temperature of spoon and viscosimeter, and height of pour. The record on the heat card is tabulated in inches of flow.

105. Slag formation in the acid furnace differs somewhat from that of the basic furnace in that lime is charged in the beginning of the basic heat to form a slag but in the acid furnace nothing except sand is added for the special purpose of producing a slag when the heat is melted down. The result is that the acid furnace has much less volume of slag than the basic. The slag formed upon melting-down consists almost entirely of the oxides of elements contained in the metallic charge, notably oxides of iron, manganese and silicon, the amount of silica being augmented by erosion of the furnace banks and bottom. It is true that most operators will add sand to the bottom and banks prior to charging the heat. In most cases, sufficient time is not allowed for this sand to completely fuse, hence a considerable proportion presumably finds its way into the slag.

Chemical Composition of Slag

106. A typical acid open-hearth slag, when the bath is completely melted, will consist of approximately 50 per cent SiO_2 and the other 50 per cent of FeO plus MnO . An actual analysis is as follows: SiO_2 , 48.9 per cent; CaO , 1.5 per cent; Fe_2O_3 , 1.3 per cent; FeO , 34.2 per cent; Al_2O_3 , 1.8 per cent; MnO , 12.2 per cent. The high iron oxide content of the slag gives it a black appearance.

107. As the carbon content of the bath is lowered by the action of the iron oxide, the iron oxide in the slag is reduced and the slag color changes from black to brown to a light green color, the tint of which is affected by the amount of manganese oxide present.

108. In some cases, to obtain a slag of proper fluidity, limestone or lime is added and it may be desirable to hasten the conditioning of the slag by adding carbon in the form of coal to reduce its iron oxide content. A final slag may have a composition similar to the following: SiO_2 , 58.2 per cent; CaO , 8.1 per cent; FeO , 19.2 per cent; Al_2O_3 , 4.0 per cent; MnO , 10.2 per cent. If a high content of MnO is maintained in the slag, a composition similar to the following may be obtained: SiO_2 , 54.1 per cent; CaO , 4.2 per cent; FeO , 13.3 per cent; MnO , 25.8 per cent; Al_2O_3 , 3.3 per cent.

Slag Viscosity

109. The control of acid slags has been primarily one of study-

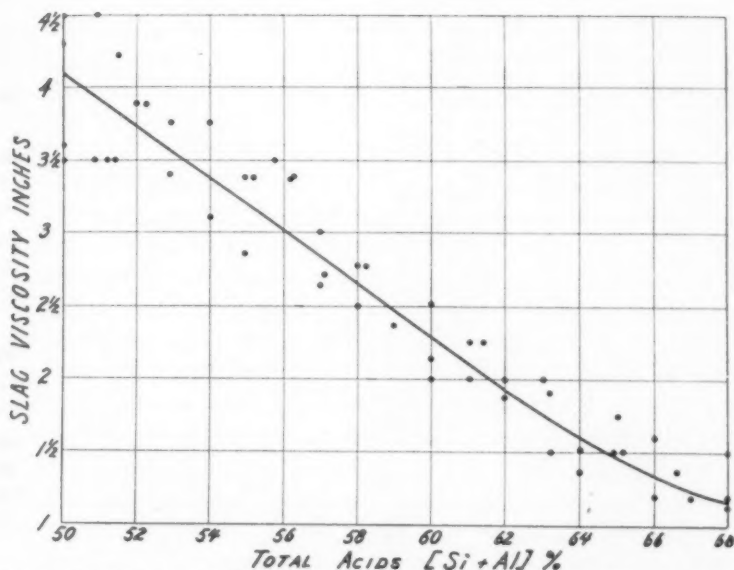


FIG. 1—THE TOTAL ACIDS (SILICA PLUS ALUMINA) OF AN ACID OPEN-HEARTH SLAG AS MEASURED BY SLAG VISCOSITY.

ing their viscosity or the manner in which slag strings out from a spoon test. Some acid open-hearth shops use the Herty viscosimeter throughout the heat. On other acid open-hearth floors, the viscosimeter is not used as the slag is so viscous, especially finishing slags, that it will not run the test channel.

110. A practice that uses 5 to 8 per cent lime in the finishing slag is desirable if readings are to be recorded on the viscosimeter. Fluidities of 2 to 3-in. can be obtained on finishing slags.

111. Perhaps the best method of controlling the viscosity of the slag is to use the proper amount of CaO or MnO and to regulate the temperature so that not too much silica is picked up from the furnace lining during the course of the heat. By regulating the silica pickup, the slag may be kept at the proper fluidity until the heat is ready for deoxidation. FeO and MnO are interchangeable so far as viscosity is concerned. It is possible, therefore, to deoxidize the slag without interfering with viscosity provided manganese is used as a deoxidizer.

112. The viscosimeter can be used at the melt-down to estimate the time of ore addition. This is an important feature, because if ore additions are made to a slag that is too fluid, it is difficult to get the slag in proper shape thereafter.

113. It is reported that one foundry has found the viscosimeter to have a very important function in the working of the heat in the early stages. They report that slags which run 4-in. or more indicate a heat that has not come up to temperature and further additions of ore are not made until the slag reaches this point.

114. Most of the acid open-hearth shops that attempt slag control, rate the viscosimeter as the important test and believe that it gives an indication of the acidity of the slag. The data shown in Fig. 1 indicates the relation between the acidity of the slag and its viscosity. A slag which runs 2-in. will in most cases have a silica content close to 60 per cent. The FeO content of the slag will depend of course on the MnO and the CaO contents of the slag.

115. The relation between slag viscosity and the total FeO content of the slag when standard charges are used is shown in Fig. 2.

116. Even though the charge and additions are standard, it will be noticed from the scattering of the points that FeO content does not depend directly on the slag viscosity. There is, however, an excellent trend indicated. It should be pointed out that this curve will apply only to the conditions of the foundry recording the data or possibly to those with closely similar practices.

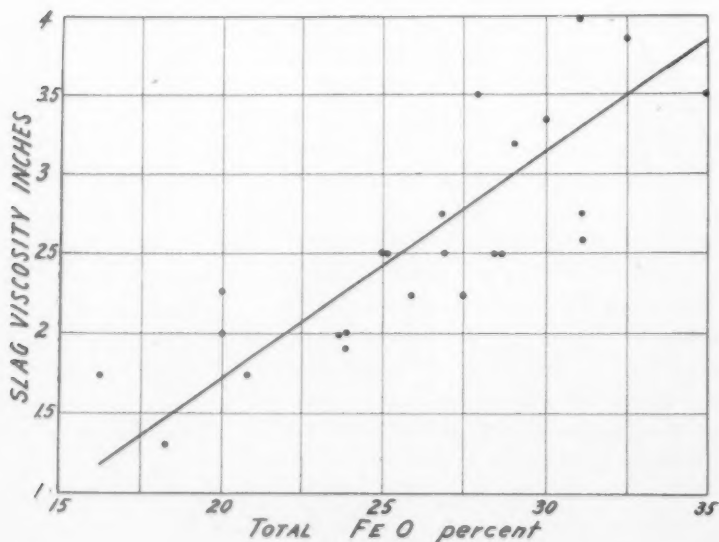


FIG. 2—RELATIONSHIP BETWEEN THE SLAG VISCOSITY AND THE FE O CONTENT OF ACID OPEN-HEARTH SLAG.

117. An attempt is made by one foundry to keep the finishing slag on steel casting heats above $2\frac{1}{4}$ -in. which means that the FeO content will be at or above 25 per cent. The reason for the relatively high FeO content is that it is believed the high FeO is necessary to obtain and maintain a steel of good fluidity during the casting of the heat.

118. Finishing slags for casting heats are sometimes kept under a 2-in. viscosity and over $1\frac{3}{8}$ -in. This means that the FeO content is below approximately 21 per cent and over 12 per cent. The low iron oxide slag permits a heat of good cleanliness with excellent manganese recovery. The FeO content of the slag is maintained over 12 per cent to prevent hydrogen absorption of the metal due to an inactive bath caused by low iron oxide content.

119. An example of the drop that may be obtained in the viscosity of the slag during an acid open-hearth heat of 130,000 lb. for steel castings is shown in Table 4.

Table 4

SLAG VISCOSITY CHANGES IN A 130,000 LB. ACID OPEN-HEARTH CASTING HEAT

Time	Additions—lb.	Carbon Content, per cent	Slag Viscosity, in.
5:05	Melted	0.76	$3\frac{3}{4}$
5:12	700 ore		
5:42		0.53	$4\frac{3}{8}$
5:56		0.41	$2\frac{3}{8}$
6:03	400 limestone		
6:20		0.23	$2\frac{3}{4}$
6:29		0.19	$2\frac{1}{2}$
6:33	1040 spiegel		
6:37	180 lime		
6:44		0.20	$2\frac{1}{4}$
6:49	1040 ferrosilicon		

120. The color of the slag is not a good indication of its FeO content since high MnO contents mask the color effect. If low MnO contents are used, then it is quite possible that the slag color can be correlated to the FeO content.

121. An indication of surface appearance and fracture color of the slag cake as a function of viscosity and composition is given in Table 5, as obtained from records on casting heats.

122. The degree of soundness of a slag cake is often studied by melters as a better indication of the FeO content than can be given

by color conditions. An unsound slag, or one of high FeO content also has greater fluidity.

Table 5
ACID OPEN-HEARTH SLAG CAKE CHARACTERISTICS

Top Surface	Pancake Bottom Surface	Fracture Color	Viscosity, in.	Composition, per cent			
				SiO ₂	FeO	MnO	CaO
Rough	Rough	Black	7¼	—	—	—	—
Rough	Rough black	Black	5¾	45.3	37.9	14.7	0.45
Smooth dull	Smooth dark	Green	3¼	50.4	29.6	10.7	5.60
Smooth dull	Smooth dark	Green	2½	54.5	24.9	10.7	5.90
Smooth shiny	Smooth shiny	Green	2¼	55.6	21.6	12.9	7.30
Smooth shiny	Smooth shiny	Green	2	56.7	20.5	12.3	7.50

123. It is believed that the surface appearance and color of the slag test do not have much significance. However, Fig. 3 shows 4 slag cakes taken at different times in the heat. Viscosity tests were also taken at the same time. The log of Table 6 gives times and viscosities for the various slag cake tests:

Table 6
RELATION OF TIME AND VISCOSITY FOR SLAG CAKE TESTS

Time		Slag Cake	Viscosity, in.	C	Mn per cent	Si
2:11	Melt-down	1	4¾	0.78	0.15	0.06
3:33	½ hr. after last ore addition	2	3¾	0.28	0.07	0.05
3:51	—	3	3	0.14	0.04	0.04
4:12	6 min. before deoxidation	4	2¼	0.13	0.06	0.05
4:30	Tap (finishing analysis)			0.28	0.73	0.37
Charge 139,800 lb.						

124. It is the experience of acid open-hearth operators that slag analyses are not of much assistance if results cannot be reported before 25 min. However, it is true that an acid slag will come to practically a constant silica content for a given temperature at a given time. Apparently, not too much information is available concerning the relation between the slag analysis and bath conditions. At present, it seems that the two can vary over rather wide limits without affecting the quality of the heat. However, when considering the limits set for heats made in the same shop, the relation between slag analysis and bath conditions varies over a com-



FIG. 3—ACID SLAG CAKE APPEARANCE. VISCOSIMETER TESTS WERE TAKEN AT THE SAME TIME AND CORRESPONDING VISCOSITIES IN IN. ARE: (1) $4\frac{3}{4}$ -IN., (2) $3\frac{3}{4}$ -IN., (3) 3-IN., AND (4) $2\frac{3}{4}$ -IN. (SEE TABLE 5.)

paratively narrow range or trouble of one type or another is encountered. The difference in furnaces, fuels, charges, products, etc., must all be considered when comparing results from shop to shop.

125. A study made of finishing slags for steel castings wherein a fluid steel is desired shows SiO_2 to be 53 to 56 per cent. In pouring large castings, where fluidity is not so important, the SiO_2 may range from 56 to 62 per cent with iron oxide content as low as 12 per cent.

126. It has been claimed that the higher the FeO content in the slag, the better the surface of the castings, consequently it is the

practice in two foundries to tap heats with as much as 30 per cent FeO.

127. It appears that for castings, acid open-hearth slags containing an FeO content from 15 to 25 per cent are quite satisfactory for the purpose intended. Acid slags tend to reach an equilibrium rather quickly, and the quantity of silica and metal oxides present is going to depend somewhat on the temperature of the slag. The equilibrium can be somewhat upset by the addition of iron ore but in a short time, equilibrium conditions will be approached again as the slag will take up silica from the banks.

128. Apparently the viscosity test is the best slag control test for the acid open-hearth furnace. It gives the operator an indication of the acid element content of the slag and it also gives a rough measure of the FeO content. It also helps the melter to maintain a slag of the proper consistency, a procedure which is difficult to do when relying entirely on its appearance as observed by the melter's eye.

ACID FURNACE LIFE

129. One of the most important items in the life of the acid furnace is the great rapidity with which the uptakes or topmost checker-work becomes choked. Serious choking usually begins in the top of the air regenerators and largely determines the length of the campaign. When the furnace schedule is interrupted at intervals to clean the checker-work, the ensuing cooling off reduces the effective life of the furnace brickwork.

130. Choking is due to an accumulation which changes in nature from a hard sponge adhering to the topmost bricks, to a fine dust at lower temperature levels in the chamber. These accumulations consist of almost pure ferric oxide.

131. Some furnace operators try to clean the checkers every 100 to 250 heats by compressed air and a long blowpipe. The accumulations are allowed to collect on the bottom of the chamber until the end of the campaign.

132. The slag pockets can be cleaned more easily and in some cases are cleaned six to eight times during the campaign. The weights of slag removed will total 180,000 lb. to 250,000 lb. per campaign to a 60-ton furnace. It has been reported that the more agitation that is set up in the outgoing gases in the slag pockets, the less material goes over into the checkers. Agitation can be increased by using a straight-faced bridge wall.

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DISCUSSION

Presiding: C. E. SIMS, Battelle Memorial Institute, Columbus, O.

Co-Chairman: JOHN HOWE HALL, Philadelphia, Pa.

H. E. DOWIE¹ (written discussion): Your paper is a complete and timely summary of this phase of steel making. I think it should be quite helpful to acid open-hearth men, and should encourage them to check their practice, with the idea of arriving at some form of standardization. It should also be very helpful to those beginning the study of acid open-hearth steel making.

¹ Mesta Machine Co., Pittsburgh, Pa.

Under the heading "*The Charge*," you state that 0.40 per cent silicon in the charge is to prevent over-oxidation and reduce the attack on the banks. It would seem to me that a much higher silicon than 0.40 per cent is necessary for this, and I wonder just what benefit is derived from 0.40 per cent silicon in the charge.

Later (page 9) the paper states "More fluid-working slags are produced with a lower FeO content." In my experience with low FeO in the slag, the SiO_2 is high and this tends to give a more viscous slag.

JOHN JUPPENLATZ² (*written discussion*): The authors are to be congratulated upon the complete work covering slag control in the acid open hearth. It is comprehensive and of practical value.

In comparing data presented, the viscosimeter is equally as useful in the acid open hearth as it is in the acid electric furnace. The silica-viscosity curves are of the same general trend that the writers presented in their paper. The data presented are limited to slags of 4½-in. viscosity or those containing 50 per cent silica and over.

The practice of oxidization in the open hearth differs from the electric furnace since longer periods of time are available for reaction in the open hearth. I believe the method of oxidization is a matter of choice either in the electric or open-hearth furnaces. Additions of liberal quantities of ore are usually made early in the electric furnace, whereas the authors use late additions of ore when the bath has attained a sufficiently high temperature to permit an intense carbon boil. Attack of the hearth by highly basic slags, low in silica, is not too severe at low temperatures. However, if there is a distinct excess of FeO remaining after the temperature has increased, permitting a rapid carbon boil, attack of the lining is severe. This phase of control is strived for in the acid electric furnace through the use of the viscosimeter during early stages of the heat or after melt-down, the slag viscosity during the early stages being adjusted with ore until the desired acidity or basicity is attained. By this method excessive amounts of ore additions can be avoided. Would this method of oxidization as used in the electric furnace be equally adaptable to the open-hearth furnace?

The authors state "an active bath should be maintained at all times to prevent the building up of gases." Experience with the electric furnace is equally true and this phase cannot be over-stressed for the production of quality steels. A slag and bath too low in FeO will be inactive, permitting gas absorption and the writer believes this slag condition should be avoided.

The authors indicate that lime is necessary in order that the slag will be fluid enough to run in the viscosimeter. The writer's experience does not concur with this statement and other acid electric producers are using the viscosimeter without the use of lime. It is believed that the silica (acid) content of the slag controls the viscosity with lime-bearing slags of CaO contents from 0 to 10 per cent.

The data as presented by the authors parallel very closely the work done by the writer in the acid electric furnace. The reactions are similar

² Lebanon Steel Foundry, Lebanon, Pa.

and the final results are comparable. Many of the variables of steel making for the production of steel castings are being harnessed by proper slag control at the melting furnace.

CHAIRMAN SIMS: Obviously, there should be some relation between the acid open hearth and the acid electric furnace, and I believe the material given here shows that to be true.

In paragraph 84 the authors say, "Viscous finishing slags prevent the absorption of non-metallics from the metal and cause a throwback of inclusions in the ladle." Is there any concrete evidence that non-metallic inclusions are actually picked up by mixing the slag and steel in the ladle? All the evidence that I have been able to gather indicates there is no danger of inclusions being picked up from that source.

P. H. SHAEFFER³: I recall where one plant was in trouble because they made their slags a little bit too thin. I believe that if you get a slag too thin in an electric furnace, where you sometimes tap the slag and metal into the ladle at the same time, and you do not control the slag viscosity, you do not really get metallic oxide inclusions, but particles of slag in the steel. The slag breaks up into such small units that some is entrapped in the finished steel.

CHAIRMAN SIMS: One of the things that prompted that question was that last week I had at least three different people from different organizations tell me that, in basic electric furnace practice, using a carbide slag, they have trouble getting low sulphur contents. This is a result of the slowness with which the slag and the metal come to equilibrium because of the lack of turbulence or circulation in the bath. There is equilibrium at the slag metal interface, but samples taken from near the bottom are quite different. To overcome this, they pour slag out first and pour the steel through the slag and thereby get a very efficient desulphurization. At first, some of them were extremely fearful that this might affect the magnaflux tests but, much to their surprise, they found it had no effect whatever.

H. H. FAIRFIELD⁴: In correlating data on armor plate, I find that when sulphur and phosphorus fall below certain percentages, the properties of cast test plates drop off considerably. I wonder if anybody can comment on what happens when you get this low sulphur and phosphorus that will account for a drop-off in the ballistic properties. The properties are apparently related to the non-metallics. It appears that what might be called an "over-refinement" of the steel takes place and there is a drop-off in ballistic properties. I would like to hear somebody comment on what happens in these slag reactions and in the melting practices and on what happens when sulphur or phosphorus are reduced to these low points.

MEMBER: Is this basic electric practice?

MR. FAIRFIELD: It seems general. Out of nine different sources of armor plate steels, it seems to be a characteristic.

R. A. GEZELIUS⁵: The restrictions on armor production are such that

³ Ohio Ferro Alloys Corp., Canton, O.

⁴ Mines and Geology Branch, Canadian Department of Mines and Resources, Ottawa, Canada.

⁵ General Steel Castings Corp., Eddystone, Pa.

we are not allowed to do too much talking. We do not agree with the use of phosphorus and sulphur on the high side. We have found that this practice leads to trouble. We intentionally keep phosphorus and sulphur as low as we can. I cannot understand Mr. Fairfield's results.

MR. JUPPENLATZ: I believe that sometimes we have tried, especially in the acid and electric furnace, to make too clean a steel, and under the microscope it does seem clean. As a matter of fact, it is difficult to find any inclusions that are very large. The physical properties, and I am not speaking of ballistic plates or armor plate particularly, are not as good as one might expect. As a matter of fact, the ductility is always on the lower side. Just why is still a question because under the microscope you see nothing except clean steel but apparently between each austenite grain boundary there is something that does not permit the elongating of the grains or their cohesion under stress. With a little bit dirtier steel, this material or film that is surrounding these grains, seems to coagulate and form dirt spots. Better ductility results. Possibly in some cases, we have tried to make too clean a steel for the properties that we are trying to make.

H. E. CRAGIN, JR.⁶: In connection with the relationships shown between the viscosity and the various elements that make up the slag, has there been any attempt to control the variables in the slag, or were the graphs worked up with a number of variables, all of which changed as the graph was plotted? In other words have you held the iron oxide, silicon and lime constant at the same time you varied the manganese oxide or have all elements varied at the same time? If that is true, are there not considerable errors produced in attempting to plot such a group of graphs?

MR. BRIGGS: All of the constituents varied, and there is considerable error in trying to plot such a graph.

W. FINSTER⁷: We feel very much the same as Mr. Briggs, that even though graphs of this type may contain considerable error due to varying conditions, they do establish the trend of changes in slag composition as measured by the viscosimeter. We have used the viscosimeter for quite some time and have found that it is a tool to which the melters take quite freely. Especially in these times when we are all faced with the problem of training more men, we consider it an important tool. The results of the test can be marked on the heat sheets in definite figures, doing away with remarks such as "slag creamy" or "slag watery," or remarks on the color of the slag, and the melting supervisor has a much better picture of what happened during a heat.

CO-CHAIRMAN HALL: There is just one point in Mr. Briggs' paper that I would like to comment on. He says that a certain practice is used especially in manganese steel to give fine grain. I suppose that means austenitic manganese?

MR. BRIGGS: Yes.

MESSRS. BALDWIN and BRIGGS (*authors' closure*): In reply to Mr.

⁶ Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

⁷ Reading Steel Casting Div., American Chain & Cable Co., Reading, Pa.

Dowie we wish to point out that the sentence of paragraph 42 beginning with "These values are believed necessary to prevent over-oxidation of the bath and reduces to a minimum the attack on the silicious banks and bottom . . ." refers to silicon contents of 0.60 to 1.00 per cent in the bath and not to 0.40 per cent as interpreted by Mr. Dowie.

The statement made in paragraph 60, "More fluid-working slags are produced with a lower FeO content," is based on the condition of steel containing a high manganese content in the bath and a high MnO content in the slag. The reason for this fact is explained in detail in paragraph 61.

We thank Mr. Juppenlatz for his discussion of the paper. We were much interested in the results he presented in his paper on acid electric slag control and we noticed that the viscosity values we presented were quite similar to those shown in his paper.

The Arrangement of Cores, Blow Holes, and Vents for Blowing Purposes

By R. F. LINCOLN*, CLEVELAND, O.

Abstract

The Patternmaking Division of the Association, realizing the increasing importance of core blowing for production work in the foundry, solicited this paper on the discussion of fundamentals connected with the construction of core boxes for and blowing operation of the core blowing machine. The paper discusses the basic principles involved. The author first reviews the operation of the core blower as a whole. Air pressures are discussed, some attention being given to the desirability of having tight seals and joints in the core boxes. Special attention is then directed to the general layout and arrangement of the core in the box and five important factors are listed. Examples are shown illustrating these factors. Gang boxes, blow hole arrangements and locations are discussed. In addition to the paper there is given a glossary of terms coming into use with the advent of the pneumatic core blower.

1. The use of core blowing machines for the fast economic production of high quality cores is becoming increasingly common not only in the larger production foundries but in the smaller semi-production shops as well. A working knowledge of the essential factors of core blower operation and methods should therefore be of timely interest to patternmakers, foundrymen and all who are working in the casting industries.

2. In this connection it is our observation that the question which arises most consistently relates not to the core blowing machine itself or to its mechanical functions, but rather to the arrange-

* Osborn Manufacturing Co.

NOTE: This paper was presented at a Patternmaking Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 20, 1942.

ment and preparation of the core box equipment for use with the core blowing machine.

3. When confronted with a job which is to be produced on a core blower, a machine of the proper size can be found available and the requirements of the finished core are pretty well known in advance as far as sand mix, strength, permeability and other physical characteristics are concerned, but the thing which seems to be most often in doubt is—"How shall the core be placed in the core box and how and where shall the blow holes and vents be arranged to give satisfactory result with a minimum of experimental effort." In view of the innumerable sizes, shapes and contours of cores used in the foundry, it is not unreasonable that confusion might be expected in deciding just what is the best way to rig any given core for blowing purposes. However, as in most other problems there are certain basic principles which may be used, and the purpose of these remarks is to impart to you some of the facts which experience causes us to believe offer a reliable guide in helping to decide the best way

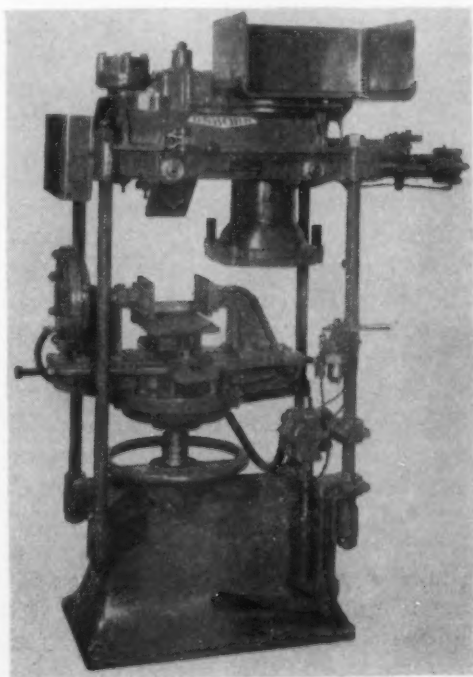


FIG. 1—MODERN CORE BLOWING MACHINE.

to go about the blowing of any core, and the arrangement of blow holes and vents which will give best results in the blowing operation.

4. For the benefit of those not familiar with core blowers, a brief description of the operation as a whole may be helpful.

PNEUMATIC CORE BLOWER

5. Fig. 1 illustrates a modern pneumatic core blowing machine suitable for the production of small and medium size cores, this being typical also of other and larger sizes. The core blowing machine is a self-contained unit consisting principally of a sand reservoir and blow plate arranged to travel back and forth from the filling position to the blowing position. This reservoir and blow plate is mounted on a carriage in the upper structure of the machine which is in turn supported by a frame mounted on a base. In the base is housed the machine table and vertical clamping mechanism.

6. In the filling position the throat of the sand reservoir is open to receive sand from the hopper, this being the position in which the box is placed in the machine. When the reservoir is moved to the blowing position the throat of the reservoir is under a sealing ring and directly over the core box. Preparatory to the blow, the vertical clamp diaphragm raises the machine table and core box, the core box in turn engaging the blow plate so that the reservoir is raised against the sealing ring in the head of the machine thus forming a tight seal between the throat of the reservoir and the blow valve chamber, and between the core box and the blow plate.

Vertical Parted Cores

7. When vertically parted core boxes are used horizontal clamps function in unison with the vertical clamp to hold the two halves of the core box together and complete the external seal, while an unobstructed opening remains for passage of the sand from the reservoir, through the blow holes in the blow plate and into the core box cavity.

Air Pressures

8. Cores are blown by applying compressed air by means of a blow valve in the head of the machine, onto the sand in the reservoir. Air should be introduced through this blow valve at a pressure of from 90 to 125 lb., thus causing a stream of sand suspended in air to be forced out of the reservoir through the blow holes into the core box cavity.

9. This stream of sand suspended in air enters through the blow holes at high velocity, and the core is rammed by abruptly arresting the travel of the sand grains, while allowing the air stream to continue on to atmosphere. This is accomplished by means of vents in the core box arranged so that the sand grains will be trapped while the air stream is allowed to pass on out of the box.

Tight Seal

10. The nature of the operation just described requires that, in addition to first class metal core box equipment with well fitted joints throughout and sufficient land to insure a tight seal at the parting line and around the blow holes, it is exceedingly important that the blowing stream be applied to the core in the most advantageous manner and that the blow holes and vents be of proper proportion and properly located if satisfactory cores are to be produced. It is the purpose of the present subject to deal principally with these three factors and for the purpose of clearer understanding these remarks will be divided into three parts relating to the arrangement of the core in the box, the arrangement of the blow holes, and the arrangement of the vents.

GENERAL LAYOUT AND ARRANGEMENT OF THE CORE IN THE BOX

11. In deciding on the best way to arrange a core in the core box for blowing purposes, it should be kept in mind that the elapsed time for the operating cycle of a core blower is approximately from 4 to 7 seconds, depending on the size of the machine. In this short space of time the core is actually made, and any additional time between the operating cycle and the production cycle is consumed in handling the blown cores and getting the core boxes in and out of the machine. It is obvious, therefore, that in order to obtain maximum productivity, the machine must be kept operating as continuously as possible.

Ease of Handling

12. This requires that core boxes should be of a size which the operator can readily grasp in his hands and the weight kept within a limit which will not cause undue fatigue to the muscles of the hands, wrists and arms due to the constant repetition of the operation. In the case of irregular shaped boxes or boxes of a width which the hand cannot span, speed and convenience of handling

can be materially enhanced by the addition of handling lugs or finger holes.

13. In the case of medium and large cores it is at once apparent that they should be rigged one core per box. Under these conditions there is little choice as to core box size and any help in balancing the operating and production cycles must be vested in core box design or mechanical handling equipment such as rollers, auxiliary rollover machines, draw machines, etc., to do the handling. However, in the smaller cores where several cores may be produced in a multiple or "gang" box there is quite often a tendency to put too many cores in one box on the assumption that because the machine will fill the box at one blow operation, the production cycle will be in proportion. As a rule, this does not work out, and in the case of gang boxes, more good cores will result from the day's run when the core boxes are kept of a size which the operator can grasp and handle without muscular fatigue.

Layout of Box Equipment

14. In laying out the core box equipment for any blowing job it is, therefore, important that careful consideration be given to the speed and convenience with which the equipment can be handled, and where mechanical handling equipment is not used, more cores per day will be obtained from two smaller, smoother running boxes operated in a reciprocal manner with one box in the machine being blown, while the cores are being transferred to driers and the second box prepared ready to immediately replace the blown box when it is removed from the machine, than from a single larger and more awkward box containing double the number of cores.

15. Working in this manner the machine is not necessarily idle during the full handling cycle for, as the blown box is removed, a duplicate box is immediately placed in the machine and as the operator turns from the machine for the purpose of placing the drier and drawing the first box from the core, he depresses the blow pedal and the machine proceeds to complete the operating cycle of clamp, blow, and unclamp on the second box while the operator is working with the first.

Automatic Valve

16. An automatic operating valve requiring only a single motion of the operator's hand is sometimes used where it is desirable to obtain the maximum speed when two or more identical boxes are

being run. The objective is, of course, to keep the core blowing machine operating as continuously as possible and the tempo of a core blowing operation is important and should be kept in tune with the mechanical cycle of the machine.

Decision on Position

17. In deciding the position in which the core can be blown to best advantage it will be well to keep in mind the following points:

- (1) It is obvious that the core must be arranged so that the parting line will permit the core to be removed from the box after it is blown.
- (2) It is always desirable to direct the blown stream downward toward the larger sand sections, rather than depend upon the venting arrangement to pull the sand up into pockets.
- (3) Wherever possible the blow stream should be introduced through the print sections of the core.
- (4) It is desirable to utilize to the greatest possible extent the natural venting possibilities of the box at the parting line or on open print surfaces thus keeping the necessity for additional venting to a minimum.
- (5) Where two or more cores are placed in one gang box they should be arranged so that each individual core has its own free venting system to atmosphere thus discouraging any tendency for the blow stream to travel from one core box cavity to another.

EXAMPLES

18. Examples of the above points are illustrated in the following manner:

Simple Cores

19. The illustration of Fig. 2 shows an ell fitting core and core box. It will be noted that the job is laid out in such a manner that the print ends are brought through the top of the box and the blow stream introduced through these print openings and directed down into the body of the core. The box is parted on a line extending entirely around the core. Blown in this position the only vents necessary are small groove vents on the parting line which may be placed at any desired point around the core.

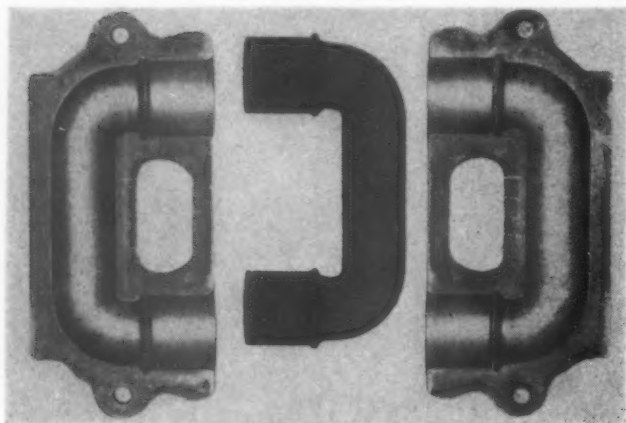


FIG. 2—ELL FITTING CORE WITH CORE BOX.

20. The fact that the prints extend through the top of the box gives further venting capacity and insures the prints coming full and with sharp edges. This method of constructing the box for this job may be compared with the old booking method on the bench, where a number of cores were made in a box, the cores being placed horizontally and each cavity completely closed in. While it might be possible to blow cores in a box of that kind it will be readily seen that the first method of rigging provides a box which is inexpensive to construct, gives the blow stream a good sweeping action and makes the venting problem quite simple. The example of Fig. 3 is one which shows a valve body core. Here again the print sections of the core are brought through the faces of the core box and the blow stream introduced down through the prints into the body of the core. The parting line permits simple groove vents on both sides of the core and the open prints provide further vent-

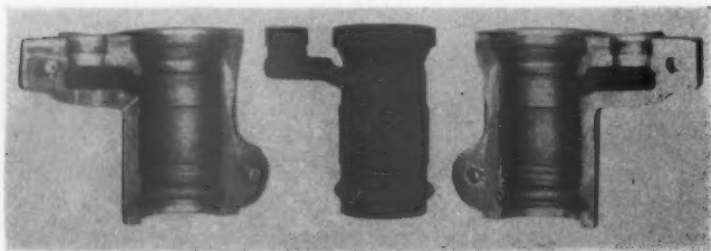


FIG. 3—VALVE BODY CORE WITH CORE BOX.

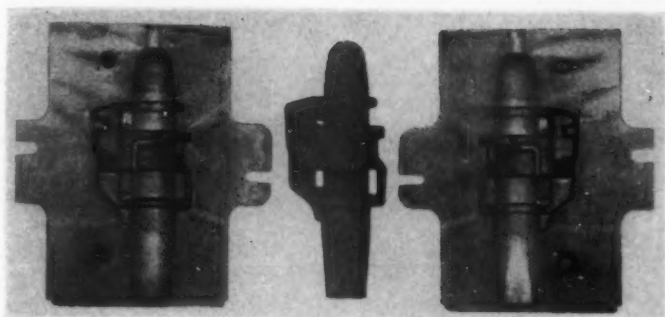


FIG. 4—MOTOR END BEARING CORE BOX.

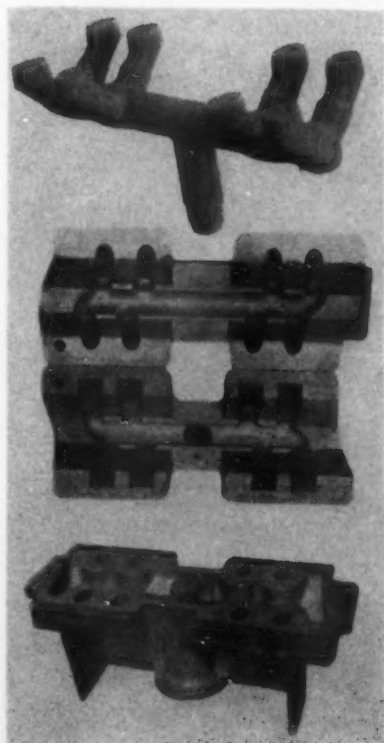


FIG. 5—AUTOMOTIVE MANIFOLD CORE WITH CORE BOX.

ing capacity under the blow plate and over the table wearing plate on the machine table.

Motor End

21. A third example of these basic principles of arrangement is the motor end bearing core shown in Fig. 4. Here again the core is placed in such a position that it can be blown by a single blow stream directed down through a print end, into the body of the core. These prints could not be brought through the outside of the box but the parting line extends entirely around the core and any point on the outline can be reached by a simple vent.

Manifold Core

22. Fig. 5 shows a Ford manifold core with core box equipment. The illustrations previously given have all been of relatively simple cores having even parting lines along which adequate venting capacity could be obtained. This manifold core is somewhat more complicated but it will be noted that the same principles have been applied.

23. An uneven parting line has been carried entirely around the core with the exception of the center leg. The eight prints have been brought up through the top of the box and the blow stream directed down through these print openings to give a good sweeping action to the main body of the core. The center leg is vented by a large screen vent placed in the bottom of the box directly under the leg. If it were attempted to blow this core from the opposite side with the prints closed in, a much more difficult problem would exist and extensive venting would be required.

Gang Boxes

24. With regard to the layout for "gang" boxes containing more than one core cavity, these same principles should be observed. Fig. 6 shows a hub core box arranged to blow three cores at a time. It will be noted that the cores are blown on end, and that the prints have been brought through the faces of the box. The blow stream is directed through these print openings down into the body of the cores. It will be noted that each core has its own individual venting system to atmosphere and extreme care should be taken in boxes of this type to insure a tight seal between the core cavities so the blow stream will not travel through from one to the other. Attempts to use large flat core boxes with a number of cores placed horizontally

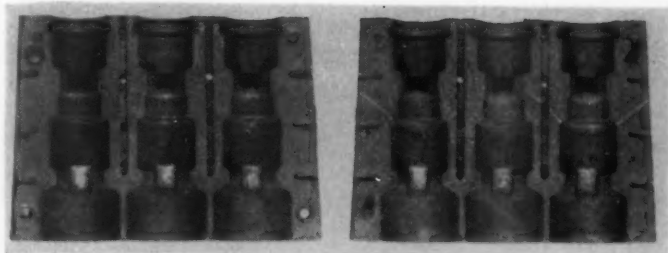


FIG. 6—HUB CORE ARRANGED IN GANG BOX.

at random and blown through the top, have proven unsuccessful. As previously mentioned consideration should always be given to the size and weight of "gang" boxes and the proportions kept within limits where the handling of the boxes can be kept in tempo with the machine cycle.

25. There is much that can be said with regard to the design and construction of core boxes but it is intended under the immediate subject to limit core box references to the foregoing remarks relating to the orientation and positioning of cores. The points mentioned should be followed as far as possible in preparing any core for blowing purposes.

BLOW HOLE ARRANGEMENT

26. In considering the arrangement of blow holes it should be kept in mind that the stream of sand suspended in air enters the core box cavity through relatively small openings under a blowing pressure of from 90 to 120 lb. and consequently travels at a relatively high velocity. Upon passing through the restricted openings of the blow holes, there is an immediate expansive action of the blow stream to fill the space made available by the cavity in the core box. This action approaches an explosive condition causing the sand grains to rebound from the points of contact with the inside walls of the core box and to exert a general whipping action.

27. Upon being released to the relatively lower pressure of the core box cavity it is assumed that there is an initial drop in the velocity of the blow stream with the result that a portion of the sand grains find permanent rest, the core box cavity filling first directly under the blow holes. Then, as the cavity fills and the available room for the passage of air becomes progressively less, the velocity of the blow stream increases in the attempt to return

to the ultimate, and the remaining portion of the sand grains tend to follow the direction of the air stream in which they are partially suspended. As the natural flow of the air stream is toward atmosphere through whatever outlets are available, it is further assumed that those parts of the core farthest from the blow holes and closest to the vents fill last.

28. In order to maintain a sufficient velocity of the blow stream, blow holes should not be too large and the average sizes used are usually from 3/16- to 3/4-in. in diameter.

Location

29. It should be remembered that wherever possible it is desirable to locate blow holes on print sections and directly over the heaviest sections of the core. When starting out to blow any job for the first time, it is well to first place, say, 5/16-in. blow holes opposite the heavier sections of the core locating them, as above mentioned, on print sections whenever possible. Paper shims on the parting line should be used as temporary vents and the blow operation tried out.

30. Sand does not flow readily around corners or through restricted passages, and after observations have been taken, additional holes should then be added opposite restricted sections, or present holes enlarged at points opposite the heavy pockets. After a few trial blows the holes may be adjusted to obtain the proper balance of volume.

Sewing Machine Head

31. A body core for a sewing machine head, together with the core box, is shown in Fig. 7. It will be noted that it has been possible to locate all blow holes on print sections. A single large blow hole feeds the main body of the core while two similar holes feed the larger print end, and two smaller holes the other print end to obtain a satisfactory balance.

Typical Blow Hole Conditions

32. The illustration in Fig. 8 shows several typical blow hole conditions. At the left is shown a blow hole located at end of print, flush with top of box. In the center, a blow hole is shown extending down through a deep section of the core box. At the right are shown two arrangements under conditions requiring only a short extension through the core box. Under all conditions it is recom-

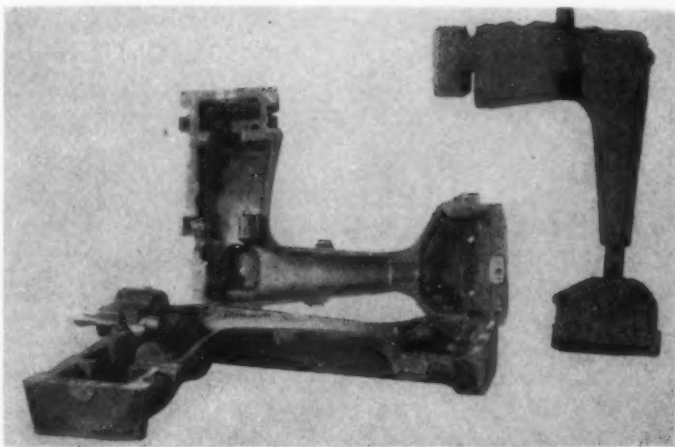


FIG. 7—SEWING MACHINE HEAD CORE WITH CORE BOX.

mended that the blow holes be counter-sunk from the reservoir side of the blow plate. Blow holes should also be bushed, preferably through both blow plate and core box sections but particularly where they extend through sections of the core box. It is good practice to provide bushings of generous wall thickness so that the blow holes can be enlarged if found necessary. It is interesting to note also that the length and construction of the blow hole passages has a marked effect upon the pattern of the blowing stream much after the manner in which a long barrel full choke shotgun will

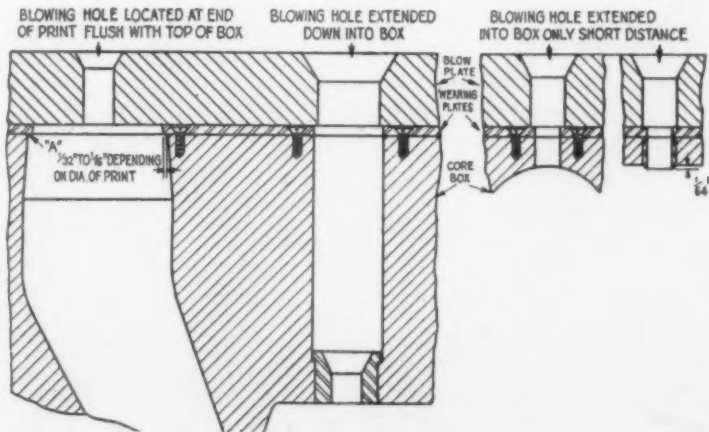


FIG. 8—TYPICAL BLOW HOLE ARRANGEMENT.

outshoot a short cylinder bore. Ramming results can be largely controlled by the length and construction of blow hole passages.

ARRANGEMENT AND LOCATION OF VENTS

33. The principles governing the venting of a core box for blowing purposes are based on the theory that the core is formed by introducing at a relatively high velocity, a stream of sand, suspended in air, through the blow holes into the core box cavity. The core is rammed by abruptly arresting the travel of the sand grains while permitting the air stream to pass through to atmosphere. It is therefore necessary that air be permitted to exhaust from the core box in a proportion at least equal to that at which it is introduced. Venting capacity must therefore be in balance with the blow holes. Contrary to a common logical assumption, when cores come soft, it is usually due to lack of sufficient venting capacity rather than lack of blowing pressure. Core boxes should be freely vented, too much vent being more desirable than too little.

34. The purpose of all vents, as related to core blowing, is to trap the sand grains in the core box cavity and at the same time permit the air to pass on out of the box. This venting of the box is accomplished in various ways extending all the way from the natural leakage at the parting line on up to ingenious and specially manufactured devices for exhausting the air from the box. Some of the more commonly used methods of venting are shown in the following illustrations.

35. Fig. 9 illustrates the simple slot and groove type of vent which consists of either a shallow groove or slot on the face of the

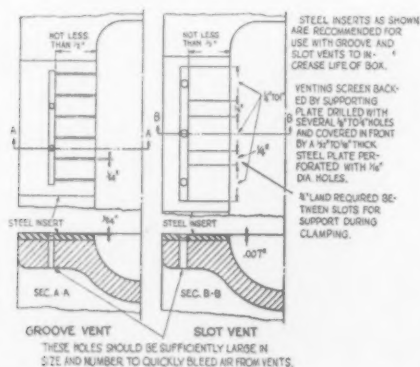


FIG. 9—TYPICAL VENT ARRANGEMENT OF THE SLOT AND GROOVE TYPE.

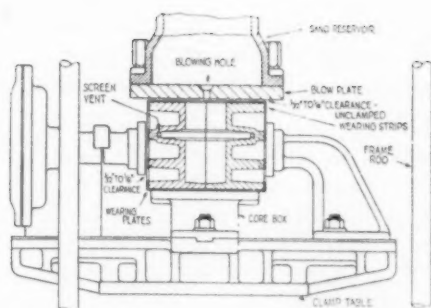


FIG. 10—TYPICAL VENT ARRANGEMENT USING SCREEN PLUS TYPE VENTS.

parting line of the core box. When the groove is used, the depth of the opening is usually about $1/64$ -in. The slot type of vent for normal use is about $1/4$ -in. wide by $.007$ -in. in depth. This is the most commonly used method of simple venting, it being possible to place vents of this type anywhere on a parting line. Good practice calls for about 2-in. of land where these vents are used and it is best to merge such vents into a single cross channel which in turn has outlets at right angles to the original direction of the air stream. In this manner the passage of the air stream is arrested and diverted so that the cutting action of minute particles of sand remaining in the air stream will be minimized. If these vents are extended entirely across the face of a parting line in a single direction, the abrasive action of the air stream will tend to enlarge the vents and destroy their purpose.

36. The use of small plug vents such as are commercially obtainable is illustrated in Fig. 10. In this view the location of the

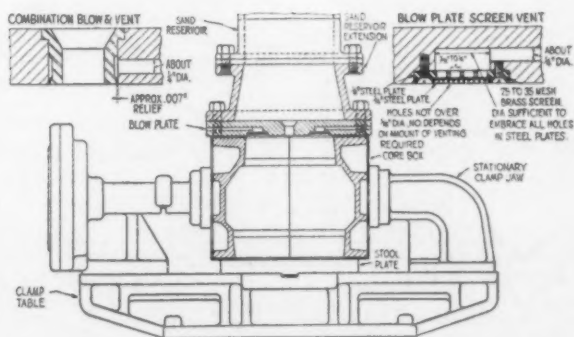


FIG. 11—TYPICAL VENT ARRANGEMENT FOR VENTING THROUGH BLOW PLATE.

two bosses on the core make it desirable that the blowing stream be diverted for the purpose of obtaining a firm core at these points, and plug vents have been placed in the core box to induce the flow of sand to these points.

37. In the case of an open top core box it is often necessary to vent the box through the blow plate and Fig. 11 shows how that may be accomplished so that the core will come full with good firm edges. At the upper right is shown a conventional method of venting through the blow plate. At the upper left is shown another way to take a vent off the top of a core by utilizing a blow hole as a combination vent thus simplifying the work in preparing the box. It will be noted that in this combination blow hole and vent, the bushing of the blow hole has been relieved by a flat channel along the outside diameter to provide an outlet from the core cavity and this outlet carried on out to atmosphere by a connecting hole drilled through the blow plate. Thus, sand enters the core box cavity through the bushed hole while at the same time air escapes from the cavity by means of the outlet along the outside wall of the bushing.

Merging of Blow Stream

38. Still another condition is illustrated in Fig. 12. Under the normal blowing action, this core would come soft where the two blow streams merge on top of the core and also at the foot of the

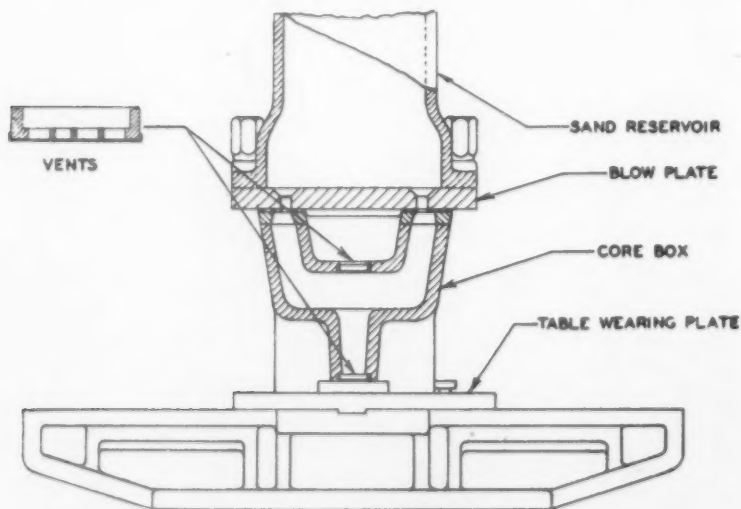


FIG. 12—TYPICAL VENT ARRANGEMENT USING LARGE SCREEN TYPE VENTS.

center leg. The blow stream must be diverted to these two points if a firm core is to be obtained and large vents must be placed in the core box at these points to force the blow stream in the desired direction.

SUMMARY

39. The foregoing are a few examples of core box vents and venting. The proper arrangement of venting for any given job is the most difficult thing to decide in advance, and best final results are obtained only by a certain amount of experiment. It is advisable always, however, to first take advantage of the degree to which the core will fill from the blow stream and natural leakage of the box plus such simple venting as may be applied on the parting line. Then use such additional special venting as may be necessary to divert the blow stream to certain parts of the cavity until the entire core fills full and firm.

40. While the foundry is constantly confronted with a never ending multiplicity of core shapes and sizes each one of which is, in the final analysis, a problem in itself, it is believed that an understanding of the different factors and how they work helps a lot on any job, and the next time any of you have occasion to rig a new job for a core blowing operation, we hope that perhaps something which we have been privileged to say here may help you to more quickly decide the best way to blow the core and the shortest cut to proper blow hole and vent arrangement.

Glossary

The following terms are defined for the purpose of clarifying the author's meaning in the foregoing remarks.

1. *Blow Plate*

A blow plate is a cast iron plate usually about 1-in. thick and shaped to follow the outside contour of the sand reservoir. It is attached by means of cap screws to the bottom flange of the reservoir and is the surface which engages the top of the core box when the box is raised by the vertical clamp diaphragm. Blow holes are drilled through the blow plate to provide channels for the passage of sand from the reservoir to the core box cavity.

2. *Blow Hole*

Blow holes are the holes drilled through the blow plate and through the top of the core box to provide passage for sand from the reservoir to

the core box cavity. The holes in the top of the core box must be in alignment with the holes in the blow plate.

3. *Core Box*

The core box is the pattern and is constructed in two halves with proper pins and guides and arranged much the same as the cope and drag halves of a mold so that the finished core can be removed. The cavity in the core box represents the form or pattern which is to be reproduced in the finished core.

4. *Vertical Clamp Diaphragm*

In order to produce a core by the blowing method it is necessary that a tight seal exist between the core box cavity, the reservoir containing the sand, and the blow valve chamber into which the air is introduced. The vertical clamp diaphragm raises the machine table a distance sufficient to overcome the working clearances and causes the top of the core box to engage the blow plate which in turn raises the reservoir against the sealing ring and completes the necessary seal.

5. *Horizontal Clamps*

In cases where the core box has the two halves parted vertically, the horizontal clamps hold the two halves of the core box tightly together. Horizontal clamps function in unison with the vertical clamp diaphragm.

6. *Hopper*

The hopper is located on top of the core blowing machine and is referred to as the receptacle for receiving and storing reserve sand from which the reservoir is intermittently supplied.

7. *Land*

Land is the bearing surface between the two halves of the core box along the parting line, and the bearing surface between the blow plate and the top surface of the core box around the blow holes, in the latter case usually provided by supporting bosses incorporated in the core box construction.

8. *Operating Cycle*

The minimum elapsed time required for the core blowing machine to complete the necessary mechanical functions if allowed to perform without interruption.

9. *Production Cycle*

The time required for the machine to perform the operating cycle plus the time required to place driers, and remove the core from the core box, and transfer the cores to the racks. In other words, the rate at which cores are produced.

10. *Parting Line*

The line on which the two halves of the core box are divided in a manner which will provide proper draft so that the core can be removed from the box.

11. *Plug Vent*

A small cup shaped plug commercially available on the market and ranging from approximately 3/16- to 3/4-in. outside diameter, the closed end of which is provided with outlets equivalent to a 30 or 40 mesh. The vents commonly obtainable are constructed in three ways. The "screen" plug vent is made from a tube with a screen disc brazed over the opening on one end. The "slotted" plug vent is made from a solid rod drilled part way through and the remaining wall cut by a series of open slots across the bottom of the cup. A third method of constructing plug vents is to form them on a punch with the bottom of the cup perforated.

12. *Sand Reservoir*

The chamber on a core blowing machine in which the sand is confined when the air pressure is applied to it, and from which the sand and air are expelled to form the blow stream.

13. *Screen Vent*

A vent in principle similar to the plug vent but usually of considerably larger diameter and constructed of a copper screen disc or perforated plate held between retaining collars.

14. *Sealing Ring*

A rubber gasket located in the head of a core blowing machine, against which the upper flange of the sand reservoir is pressed during the clamping operation. This sealing ring provides the element of resiliency necessary to complete a tight seal between the several parts affected.

15. *Table Wearing Plate*

A wearing plate mounted on the machine table of a core blowing machine to absorb the frictional wear resulting from the constant sliding of the core box in and out of the machine. The table wearing plate protects the more costly machine table and may be readily replaced from time to time. For large heavy jobs the wearing plate is provided with rollers to reduce the frictional wear.

16. *Vent*

Vent, as used in these remarks, is intended to refer to any means used to exhaust air from the cavity of a core box while at the same time tending to trap the sand grains within that cavity.

DISCUSSION

Presiding: FRANK C. CECI, Cleveland Trade School, Cleveland, O.

Co-Chairman: V. J. SEDLON, Master Pattern Works, Cleveland, O.

MEMBER: What is the approximate size of the head on the core box?

MR. LINCOLN: We build a number of different sizes of machines. The blow plate might be anywhere from 15- or 16-in. in width up to 40-in. in length, or, for some special application, larger. The blow plate should

be of sufficient area to provide blow holes in the top of the core box, wherever it may be necessary to locate them. In other words, if it is a big, wide job, it would be necessary to get the blow holes distributed over the area of the core cavity.

MEMBER: In other words, the hood must be the right kind for a core box of a certain size.

MR. LINCOLN: Yes.

MEMBER: Is the same machine applicable for hoods of a different size?

MR. LINCOLN: Within limits. The physical clearances in the frame of the machine are what have to be watched. The travel of the reservoir can be so much and the reservoir should clear the core box when it is in the filling position. In some cases, where we blow several cores from the reservoir without refilling it, this reservoir remains in the blow position and the different boxes are sent in and out until it is necessary to get another supply of sand. Core blowing machines are built in a number of different sizes.

M. J. GREGORY¹: We blow 200 every day of about 300 lb. apiece.

MR. LINCOLN: That is the largest I have heard of. We are up to better than 200 lb.

MEMBER: I had in mind the venting of a core which has been taken care of as far as blowing is concerned. When blowing directly into the vent and it is necessary to vent the core to let the gas escape when the molten metal goes around it, how is the venting taken care of?

MR. LINCOLN: If it is desirable to vent a core after it is blown, it might be done down through the blow hole before the box is opened and placed on the drier. That is done quite often in the case of open vents. On a small job, the vent wire can be pushed right in and pulled out. On some of the larger automotive jobs, we blow the vent rods in the core and then remove them.

MEMBER: Is it removed and put in the drier?

MR. LINCOLN: The core is blown vertically.

MEMBER: Would it be simpler to blow it on the side?

MR. LINCOLN: One of the points that has been brought out is that it is desirable to introduce the sand stream down into the body of the core in more or less of a sweeping action. If it were put on the side, the box would have to have a number of blow holes. The travel of the sand would be very short, and the sand would rebound much quicker. There would be more of an explosive action in the box and it would probably be difficult to get a good, firm core.

A. K. LAUKEL²: Would it be possible to put a well on the end of the box and blow it flat?

MR. LINCOLN: It is desirable to get the longest possible travel in your blow stream.

MR. LAUKEL: Instead of blowing directly into the core cavity, or, when it is more convenient to blow the box flat than on end, the sand is blown into wells or cavities located away from the core proper, and holes

¹ Caterpillar Tractor Co., Peoria, Ill.

² Electro-Chemical Pattern & Mfg. Co., Detroit, Mich.

from these wells lead into the core cavity. In other words the sand must travel at right angles to get to the box. The original sand wear is in the well rather than in the core cavity proper.

MR. LINCOLN: The core shown in Fig. 5 is a little more complicated, but the five principles that we have been talking about were used, even though in applying them it was necessary to make a core box with an uneven parting, and the sand was introduced down through the prints into the heavier sections of the core. The parting line was such that it went practically all the way around the core, with the exception of the stem. The stem in the bottom of the core box had to have a different type vent. Aside from that, the only vent used was a simple groove vent through the parting line.

Figure 6 shows a 3-gang box and illustrates individual venting systems for each core box cavity. A groove was carried between the cores with outlets to atmosphere, and the groove vents were brought into these channels, so that virtually each cavity is a separate core box, even though they are all housed in the same main box.

MEMBER: Did you put a blow hole right down through the center on the center pin core shown in Fig. 5?

MR. LINCOLN: The marks of some of the blowing holes still can be seen.

MEMBER: That is another case where the sand must travel around the corner.

MR. LINCOLN: It is a sweeping action in a general direction, and the natural direction of the blow stream is diverted by supplementary vents.

MEMBER: Did you vent the box where it goes down into the long outlet?

MR. LINCOLN: Yes, at the base of the leg. Sand has a natural flow and, in rigging a job, at the beginning, advantage should be taken of that natural flow and, by experiment, it should be diverted only where necessary by supplementary vents. A surprising number of cores can be blown with nothing but the parting line opening in the box.

MEMBER: In connection with the core box shown in Fig. 5, I have seen it in operation and there were about 11 drag heads and probably a half dozen core packs. With the drags, it took longer to come back, but it was all done by conveyor. It does not require the same number of copes as does the drag half. The core was vented right through the plate.

MEMBER: Is there any other vent in the box shown in Fig. 7 other than the parting line?

MR. LINCOLN: It is not good core box construction but is used to show the location of the blow holes. Figure 8 shows several typical conditions under which blow holes are put into core boxes.

MEMBER: In some of the jobs that we are trying to blow, we have found that the hopper is large enough to blow the box, and we have a number of vents, but it will not fill up. When we took the plate off, we found the air had blown through the sand. What is the cause of that?

MR. LINCOLN: There might be several causes. One could be the sand mixture. One of the prime requirements of sand for blowing purposes is that it has flowability. I have been in some steel foundries where the sand has been loaded up with binders so that the sand balls up. Just so much sand can be blown out of a reservoir before it will crater through, even with flowable sand. Our opinion is that probably $\frac{1}{3}$ to $\frac{1}{2}$ of the volume can be blown out. The volume cannot always be judged by weight because it depends upon the shape of the reservoir. In other words, if the reservoir is small in diameter, more than one-third of the volume could be blown out, but a certain level over the blow holes must be maintained.

MEMBER: Is it a question of grain size of the sand?

MR. LINCOLN: I do not think so. I believe that the grain size has more to do with the physical requirements or other similar matter of the core. It is when the sand is loaded up with dextrine that a bad blowing condition results.

MEMBER: Do you mean you keep the sand more open?

MR. LINCOLN: In some places, very fine sand is being blown. The moisture content has an important bearing on it, but the sand has to flow under blowing pressure.

MEMBER: In other words, every foundry has to take its own sand and experiment with it to get the best results.

MEMBER: One of the biggest bottlenecks in the industry, with regard to the war effort, apparently is aluminum cylinder heads. Are any of the jobbing pattern shops or manufacturers of blowers doing any research in the way of attempting to blow such heads?

MR. LINCOLN: No.

MEMBER: Eventually someone will do it. It is just a question of getting a sand that will adhere and stand up. Our biggest trouble in blowing the cores is the nails that go into the heads. We place 500 nails to hold the thin plates of sand in position. Without the nails, the plates break down when an attempt is made to remove the core from the machine. A way must be found to swing the blown core from under the machine and get it onto the rack without breaking down the plates of sand.

Plaster Molds for Precision Non-Ferrous Castings

BY H. F. HAGEMEYER*, CHICAGO, ILL.

Abstract

According to evidence, given by the author in this paper, the use of plaster molds dates back to the 16th century and may even go back as far as the days of the Romans and Egyptians. He states that some of the properties of plaster which make it a suitable molding material for most non-ferrous castings are—(1) it can be controlled to have only sufficient resistance to withstand the hydrostatic head of the liquid metal and will, therefore, not interfere with the shrinkage of the latter on cooling, (2) it can be thoroughly dried at an elevated temperature before the metal is poured, and (3) it has satisfactory venting properties over the entire impression surface. Another valuable property of plaster as a mold material is that it allows a casting to be fed slowly enough so as to produce practically no turbulence, directional solidification is promoted, and all physical factors involved in the conversion can be mechanically controlled.

1. The use of plaster as a molding material is old. It has been stated by some research workers that plaster must have been used in the days of the Egyptians and Romans, and it is definitely referred to in Benvenuto Cellini's work in the casting of metals.

2. In the shaping of liquid metal into desired forms or shapes, try to picture a shape suspended in space, surrounded by an imaginary ideal forming medium just capable of holding the liquid shape in place, and then watching its temperature decline to normal. It would appear that, if the metal had been able to solidify and contract wholly within its own design or shape, and had not been subjected to any modifying or deformative forces other than those just necessary to accomplish heat dissipation, we would then be approaching the ultimate in the maximum retention of a sum total of physical values.

3. In the development of the so-called plaster mold process, this sort of picture has been kept in mind and the process has been reduced to what it is believed are the means and fundamental considerations involved so as to most nearly conform to this conception.

* Castings Patent Corp.

NOTE: This paper was presented before a Non-Ferrous Session at the 46th Annual A.F.A. Convention, Cleveland, Ohio, April 20, 1942.

CONSIDERATIONS IN THE PROCESS

Resistance of Molding Material

4. The first consideration would be that, whatever metal-forming material is used, it should be yielding, that is, have just sufficient physical strength to hold its shape against the force necessary to put the metal into place, and while the temperature is declining from the liquid into the lower plastic or solid range of the alloy, that the material then give or yield before the contracting metal.

5. The molding material used in the process under discussion, in the dehydrated state, ready for receiving metal, has a maximum resistance of 8 lb. per sq. in. The maximum hydrostatic head used or required is 4 lb. per sq. in. Most castings poured by this process, to date, require a hydrostatic head of not more than 2.5 lb. per sq. in., and it has been demonstrated that some designs can be filled with a pressure as low as 1 lb. per sq. in. The liquid pressure is more than ample to bring out the minutest details and the contracting alloy has been subjected to a deformative action of not over 8 lb. per sq. in. Where necessary, this resistance factor can usually be reduced to a point barely above the liquid pressure putting the metal into place.

Physical Properties of Mold

6. The second consideration would be that the medium used should be free from moisture or gas-forming materials so that when the liquid metal is poured into place, no ebullition or turbulence would take place.

7. The mold material used in the present process is put through a continuous, dehydrating furnace which eliminates both the free water and reduces the chemically combined water to a point where, when the metal is poured into place, no ebullition or turbulence occurs.

Venting Properties

8. The third consideration is that the metal-forming material have venting properties so that venting is over the entire area of the impression surface. It should be of such a degree as to also promote the condition that no ebullition or turbulence will take place. A dry plaster mold has a permeability of approximately one-third that of a loosely-rammed, coarse, sand mold. However,

the amount of gases, etc., is so much less in a proper type plaster mold that the venting rate is more than ample.

Gating and Riserling

9. The fourth consideration covers the hydraulic and pneumatic phases involved in guiding the metal into place in the impression. These considerations are of utmost importance, so that lamination and entrainment of oxides and the occlusion of gases are either completely avoided in articles of correct physical design or are held to a minimum where design makes this impossible.

10. Pouring molten metal into a plaster mold, as compared with a sand mold, is quite different. This is particularly true as more time can be taken to fill a plaster mold of the type under discussion as against a sand mold. The sprues, runners, feeders and risers required for a sand mold are altogether different from those which are possible in a plaster mold. A feeding method employed in a sand mold also could be used in a plaster mold and completely fill all the impressions. However, it would not produce a product of maximum physical values.

11. The feeder system employed in the present process will develop maximum physical values but would not even begin to fill a sand mold. A sand casting may be classed as a chilled casting, as compared with a plaster mold casting. In all of the non-ferrous alloys used to date, that is, the copper-base and aluminum-base alloys, it has been found that the maximum orifice necessary is 0.0007 sq. in. per ounce of metal, and in some of our experiments, it has been found that an orifice of half that size can be used and still fill the impression. The fact that the inlet to an impression can be held to such small dimensions makes it possible to control the rate of flow into the cavity so that practically zero turbulence of expanding pool of metal into place is possible.

12. Picturing it another way, the initial globule of metal entering the impression is constantly and comparatively slowly expanded by metal continuously running into the inside of the original mass of metal until the entire mold cavity is full. The surface of this globule, as it expands, is deformed by the walls of the impression, acquiring the shape of the article. This makes it possible for metal that has been exposed to atmosphere to expand to the walls of the cavity and this exposed metal does not subsequently become entrained in the body of the product.

Directional Solidification

13. The fifth consideration is directional temperature reduction or directional solidification of the metal as much as possible. Being able to control the expansion of the initial globule and its continuous enlargement into place in an orderly and non-turbulent manner would also greatly promote the obtaining of directional solidification without the introduction of other cooling means. This controlled feeding of metal into place also has demonstrated its worth in the production of pressure tight castings. From a recent test made, using this feeder system, and because in the process under discussion all the physical factors involved can be controlled, not a single pressure test failure resulted. As a result of these tests, some castings are now being made for pressure purposes by this method.

Mechanical Control Desirable

14. The sixth consideration is that all the physical factors involved in a conversion process should be mechanically, instead of manually, controlled. This is possible with the plaster mold process and is now being gradually completed.

ALLOYS USED

15. As regards alloys, to date the process has been confined almost wholly to copper-base alloys. The plaster mold process is particularly well adapted to high physical value bronzes, such as any variation of the manganese bronzes, aluminum bronzes, any form of the tobin bronzes, and silicon bronzes. Some work also has been done in the beryllium-copper alloys and, at the present time, quite a few castings are being produced in this latter metal. Licensees also are producing castings in the common yellow brass alloys. Aluminum alloy castings of maximum physical values are not yet being produced, although licensees are producing quite a few aluminum castings for service in places that are not too highly stressed.

CONCLUSION

16. Generally speaking, it is possible to cast to a fine surface, practically any combination of copper, nickel, aluminum, manganese, silicon, tin, zinc and lead, where the latter is not over 2.5 per cent, and where the pouring temperature does not exceed 2300°F., and where there is no objection to the use of 0.1 per cent of either beryllium, silicon or aluminum.

DISCUSSION

Presiding: M. V. HEALEY, General Electric Co., Schenectady, N. Y.

Co-Chairman: D. FRANK O'CONNOR, Watts Regulator Co., Lawrence, Mass.

W. ROMANOFF¹: What are the advantages of this process?

MR. HAGEMEYER: The first and chief advantage is a matter of economics. We can produce a product of greater physical value. So far, our process has been mostly used in the production of copper base alloys and is particularly well adapted to the high physical value bronzes, such as beryllium bronzes, aluminum bronzes and manganese bronzes. We can handle these alloys successfully because we have complete physical control over every physical phase of our process.

We can cut a lot of machining time. In fact, the tolerances we can cast to are very often within the range required. Teeth are cast on beveled gears about $4\frac{1}{2}$ -in. in diameter that run within 0.0008-in. We have made a lot of gears in aluminum bronze that have been very successful. Further, our process is also well adapted to making products for the war program.

C. J. LONNÉE²: Regarding labor involved, etc., how does the cost of this process compare with that of sand molding?

MR. HAGEMEYER: Sand, of course, is much cheaper than plaster. However, due to the fact that we now have, and are continuing to develop our process toward greater automaticity, our labor content is quite low as compared to the sand casting process and machining. Further developments in process will further reduce the labor content. Expressed another way, low labor content and higher material cost as against sand method low material cost and higher labor content, together with considerably higher machining cost, indicate the direction of our economies.

MR. LONNÉE: Is the material reclaimable after it is used once?

MR. HAGEMEYER: At two of our plants, we are using 30 per cent of reclaimed material. The maximum appears to be about 50 to 55 per cent.

W. P. O'BRIEN³: In doing some of the original work of reclaiming that material, we have made molds with 75 per cent of reclaimed material. However, there are some other considerations involved that apparently go into the setting of this material, and we were not able to reclaim 75 per cent of this material consistently. However, 30 per cent of this material can be reclaimed efficiently and consistently.

B. A. MILLER⁴: I would like to ask about heat dissipation in this material as compared with dry sand, cement sand, and green sand. Is the heat dissipation slower in plaster molds than in the other processes? How do the physical properties of the castings made in plaster molds compare with the physical properties of castings made in other processes?

MR. HAGEMEYER: Naturally in a straight sand mold as against a straight plaster mold, the heat will not dissipate as fast through a plaster mold as it will through a sand mold because water is used as a bonding

¹ H. Kramer & Co., Chicago, Ill.

² Muskegon Piston Ring Co., Sparta, Mich.

³ W. D. Allen Mfg. Co., Chicago, Ill.

⁴ Cramp Brass and Iron Foundries Div., Baldwin Locomotive Works, Philadelphia, Pa.

means in sand, and, naturally, the expanding of water dissipates heat. We can spray a moisture coating on our dry plaster molds and use it as a means of dissipating heat, but we do not believe that is the right way to do it. We are currently developing another process to give whatever heat dissipation rate is desired for a given geometric shape of casting. If water is used as the means, it cannot be controlled over the entire area of the impression uniformly. There is bound to be a variation in temperature rate. We think there is another way of doing that.

MR. MILLER: Then, with this process, the critical ranges are lengthened somewhat?

MR. HAGEMEYER: That is right. In other words, we do not believe in a slow cooling time, nor is it desirable to chill a casting instantly. We believe, however, that for a given geometric shape, there is a definite temperature deceleration rate or time that will give the maximum physical value.

MR. MILLER: Would you expect grain growth with this process?

MR. HAGEMEYER: If it is slower cooling, the grain size is increased. If it is a copper-base alloy, or, more particularly, an aluminum base alloy, the grain is larger.

MR. MILLER: How about manganese-bronze?

MR. HAGEMEYER: There would be smaller grain size than in the copper-base alloys without the manganese. Manganese is desirable, and so is nickel.

MR. MILLER: The real benefit, in this process as I see it, is that it permits pouring uniformly at a lower temperature.

MR. HAGEMEYER: That is right. The sprue can be located and it can be poured so that the advance of the metal is in an orderly controlled manner. There is never any skin turbulence and the outside layer or initial globules are continually being laid against the wall of the material itself. In that way, such things as oxide entrainment and gas occlusion are limited.

MR. MILLER: How large a casting have you poured with this process?

MR. HAGEMEYER: At the present time, we have a 12- x 18-in. mold with a height of 3 $\frac{3}{4}$ - to 4-in.

MR. MILLER: How much pressure would you expect the mold to stand?

MR. HAGEMEYER: We attempt to hold that at a point just above the deformation. We can go down around 8 lb. now, and we expect to raise the water content so as to reduce it to about 6 lb. because the lower the compressiveness of the material, the lower the resistance to the shrinkage of the alloy. If a casting can be cooled with a minimum of resistance, more ideal means of casting are approached.

G. K. DREHER⁵: Mr. Miller has brought up an important point in regard to the physical properties of this particular process. I know that we have had the same question in mind many times. Most foundrymen have tried to approach control of grain size as being one of the desirable goals of all practice. In his process, Mr. Hagemeyer goes into reverse a little bit on that theory, apparently with considerable success.

⁵ Ampco Metal, Inc., Milwaukee, Wis.

I would like to suggest to Mr. Hagemeyer that, perhaps, during the succeeding year, he make an effort to get a compilation of physical data. There are some alloys such as beryllium-copper, aluminum-bronze, and some others, that are seriously affected by cooling rates. Others, like manganese-bronze, are, perhaps, not so much affected. The tin-bronzes most certainly are.

MR. HAGEMEYER: All I can say is that in the copper-base alloys, our physical values in most of the alloys run higher than they do in sand, except the elongation which is usually somewhat under that obtainable in sand. The tensile strength, hardness and resistance to deflection are higher in the plaster process.

MEMBER: Will you explain a little more the results of this process?

MR. HAGEMEYER: We have cut the arms of about two dozen aluminum-bronze gears with a hacksaw and the deflection has been not over 0.003-in. at any time. This illustrates that the residual stresses and creep values are down so low that a center arm, holding this segment, will have a deflection of plus or minus less than 0.003-in.

In the sand casting, we cut a section out of the same location and it pulled over somewhere around $\frac{3}{4}$ - to one-in. The curvature changed very materially.

MR. ROMANOFF: Is it true that one of the important advantages in your process is that you do not require as much finish allowance as would be required on a sand casting, and that you are able to compete favorably with die-casting and forgings?

MR. HAGEMEYER: We are supposed to do that. Usually from 0.010- to 0.020-in. finish is ample. On a one-in. long core, we use about 0.015-in. draft, and 0.020- or 0.025-in. would be ample stock for finishing. On many dimensions, we need less than that. We can cast on a plus or minus 0.002-in. per lineal in. basis, and on many things we do better than that.

C. V. NASS⁶: The question arises as to the adaptability of the process to either low or high production, *i.e.*, how adaptable is it to one piece, a dozen pieces or 10,000 pieces?

MR. HAGEMEYER: At one licensee plant, we have jobs that run anywhere from 10 to 10,000 a day. It is merely a matter of a multiple number of impressions. We are just like everyone else in that we prefer the high production rate because it means lower supervision per unit casting.

MEMBER: How well does this mold material resist dropping of the metal, for example, in top pouring? Do you have any penetration when you drop the metal into the mold?

MR. HAGEMEYER: Regarding resistance to impact of molten metal, with our present material, the metal could drop say, 22- or 24-in. We can raise the compressive to give almost any point necessary.

MR. MILLER: At what temperature does this mold material deteriorate?

MR. HAGEMEYER: We put 2300°F. at the top. As a matter of fact, we do not think there is any particular limit to the temperature at which

⁶ Fairbanks, Morse & Co., Beloit, Wis.

a mold can be made to collapse. The collapsing temperature can be raised by using refractory materials, such as aluminum oxides, silicon carbides or similar substances. Of course, the mold cannot be made entirely of those materials. All that is necessary is sufficient resistance to disintegration for the weight. The process, naturally, is like any similar process; it prefers to make a casting of comparatively thin wall stock rather than the heavy. That is the same whether it is a steel die, sand mold or anything else.

Temperature Measurement of Molten Cast Iron With the "Rayotube" and Optical Pyrometer

By R. H. KOCH* AND A. E. SCHUH*, BURLINGTON, N. J.

Abstract

For measuring temperatures of molten cast iron an instrument, to perform under actual shop conditions, must have accuracy, precision, ruggedness, ease of calibration and economic operation. This paper describes the results of an intensive investigation of instruments to meet these requirements. An adaptation of the "rayotube" instrument, coupled with an appropriate recorder, was developed to measure the temperature of the molten metal continuously discharging into front slagging cupola spouts. The instrument, measuring the total radiation emitted from an immersed refractory tube, is described, together with its operation. It was found to meet all the above requirements for the measurement of the true temperature of molten cast iron. A further adaptation of the rayotube for quick and intermittent temperature determinations of equal reliability is under development. The simultaneous use of the rayotube with the commonly employed optical pyrometer made it possible to segregate the precision and accuracy aspects of the latter. The optical pyrometer when sighting on the free surface of molten iron has certain limitations in accuracy due to changing emissivities, and methods are shown for minimizing these errors.

INTRODUCTION

1. The reliable measurement of the temperature of molten cast iron is of importance to a foundry owing to the improved control it affords both to the melting and casting operations. This is par-

* Research Engineer and Director of Research, respectively, United States Pipe and Foundry Co.

NOTE: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

ticularly so in a foundry in which a product of uniform composition is fabricated in a repetitive process which depends to a large extent on the use of a metal having a constant viscosity at each instant of pouring.

2. An instrument for the reliable determination of the temperature of liquid cast iron day in and day out under actual shop conditions must meet the following combination of properties: accuracy, precision, ruggedness, ease of calibration and economic operation.

3. In the melting of iron in a cupola, particularly if the iron is discharged uninterruptedly, the knowledge of the continuous melting temperature permits correlations of temperature with the several significant variables affecting the performance of a cupola. For this purpose the temperature-measuring instrument should have adequate life and be supplemented with recording facilities. For the metal traffic and casting operations, intermittent temperature determinations as a rule suffice and for this purpose the speed of response of the instrument is important owing to the limited time usually available for a determination.

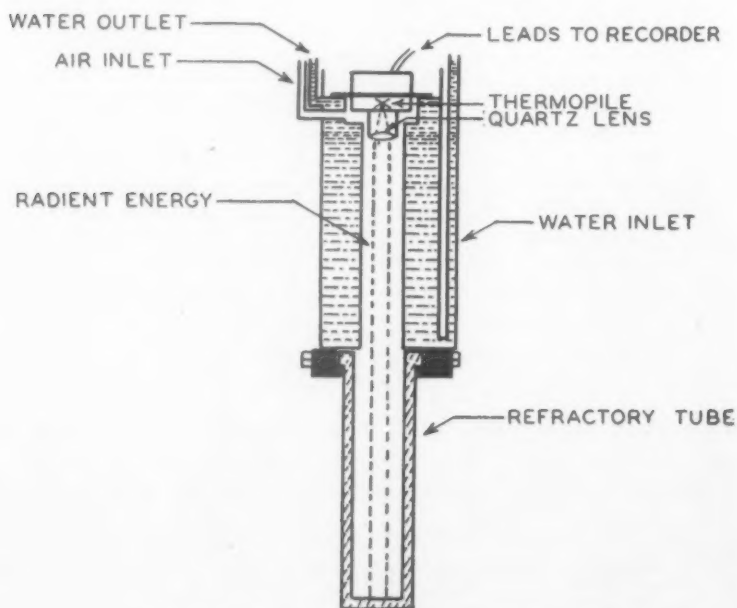


FIG. 1—CROSS SECTIONAL VIEW OF RAYOTUBE PYROMETER.

4. Of various possible instruments, two were considered for intensive investigation, inasmuch as they held good promise of fulfilling the requirements mentioned above. These are (1) the "rayotube" and (2) the optical pyrometer. An evaluation of their comparative merits and limitations forms the subject of this paper.

THE RAYOTUBE

5. In collaboration with the Leeds and Northrup Company a rayotube instrument, coupled with an appropriate recorder, was developed and appraised for its suitability to measure the temperature of the molten metal continuously discharging into front slagging spouts of large cupolas operating uninterruptedly for heats up to twenty hours in duration.

6. The high temperature rayotube instrument operates on a total radiation principle. The source of radiation is a refractory tube, closed at the lower end, which, when immersed to sufficient depth, attains the exact temperature of the iron. The refractory tube is attached at its upper end to a water cooled jacket that contains the rayotube proper. The rayotube, as shown in Fig. 1, consists essentially of a thermopile (a cascade of thermocouples), and a fused quartz lens. The energy radiated from the bottom of the refractory tube is directed onto the thermopile by the quartz lens. The heat absorbed at the thermopile by the radiated energy sets up a proportionate potential which, by proper instruments, is converted into a continuous chart record. A small stream of air is circulated through the instrument to scavenge any fumes formed which would tend to cut down the effective radiation. This air enters near the lens and passes downward through the sighting field and out at the top of the refractory tube. The rayotube was installed at the front slagging dam of continuous tap cupolas. The arrangement was such that the instrument could be readily installed at any one of a battery of two or more cupolas. Figs. 2 and 3 show the exact location of the rayotube in the front slagging well.

7. The rayotube was calibrated and checked for its accuracy with platinum-platinum 10 per cent rhodium thermocouples. Two such platinum couples were used in the calibration and checking, one of which was used only in the laboratory as a primary standard. The primary couple was regularly checked against the melting point of gold¹ to make certain of its continued accuracy and was

¹ Foote, P. D., Fairchild, C. O., and Harrison, T. R., "Pyrometric Practice"—BUREAU OF STANDARDS TECHNOLOGIC PAPER, No. 170, pp. 208-209 (1921).



FIG. 2—RAYOTUBE MOUNTED IN FRONT SLAGGING WELL OF CUPOLA.

then used to check the secondary couple which was used in the shop for actual immersion in molten iron adjacent to the rayotube. This couple was immersed to at least 10 in. and held in place to assure temperature equilibrium at all times. This secondary couple was suitably protected by an inner tube of sillimanite which, in turn, was covered by a clay-graphite tube. It was found necessary to renew this secondary couple twice during the period of this investigation because of slight contamination.

8. By repeated checking of the rayotube with the platinum couple over a period of six months, hundreds of determinations showed that the rayotube consistently stayed within the limits of $\pm 10^{\circ}\text{F.}$ of the true temperature as indicated by the platinum couple. There are, of course, possibilities of obtaining erroneous temperature readings with the rayotube. For example, if no air is

admitted, the lens will become fogged with fumes evolved by the refractory tube and a low reading will result. Conversely, if too much air is admitted the inner surface of the refractory tube will be cooled and also produce a low reading. The proper amount of air can be regulated by a small needle valve so as to eliminate this error. If the refractory tube is not immersed sufficiently it will not attain the exact temperature of the iron and again a low reading will result. An immersion calibration for the instrument is shown in Fig. 4, to illustrate the error that may be caused by insufficient depth of immersion.

9. The only cost in operation of the rayotube, other than the small amount of water and air that is used, is the periodic replace-

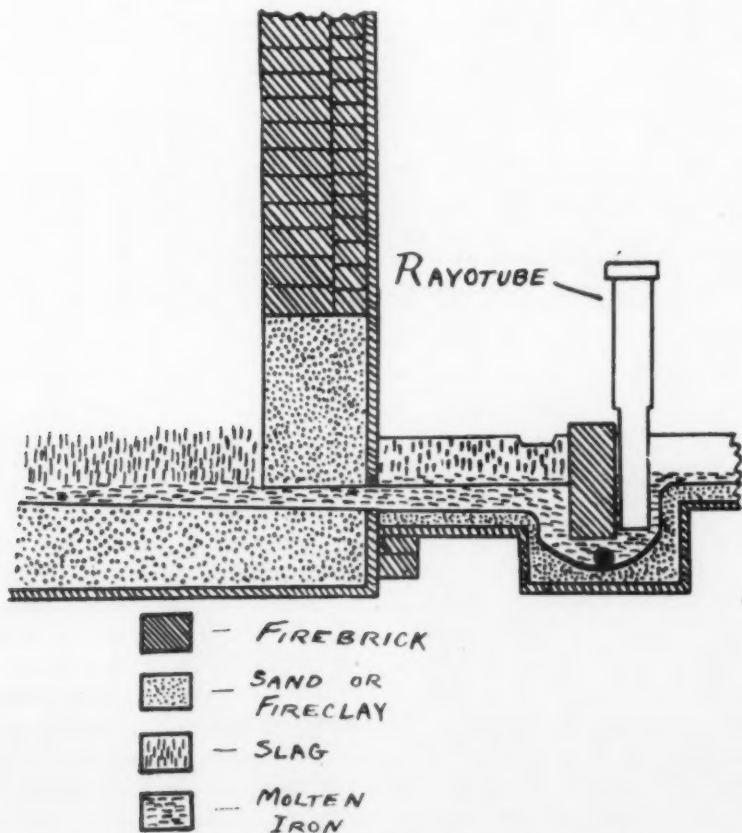


FIG. 3—LOCATION OF RAYOTUBE IN RESPECT TO FRONT SLAGGING DAM.

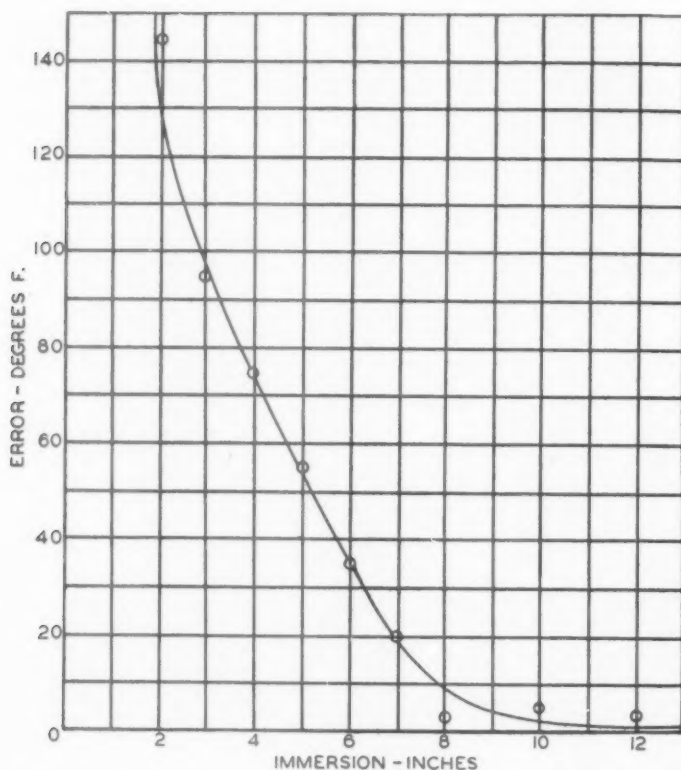


FIG. 4—IMMERSION CALIBRATION FOR HIGH TEMPERATURE RAYOTUBE. (CLAY GRAPHITE TUBE, 2 $\frac{3}{4}$ -IN. OUTSIDE DIA., 2-IN. INSIDE DIA., 16-IN. LONG.)

ment of the refractory tube. Several refractory tubes have been tried, namely, silicon carbide, electrode graphite, fused quartz and proprietary clay-graphite refractories. Of these refractory tubes, the clay-graphite has proven to be far superior when immersed in the hypereutectic irons used in the course of this study. These tubes have given an average life of three 16-hour heats of continuous immersion in the front slagging well of a cupola melting as high as 30-tons per hour. Under these conditions a refractory tube cost of less than a quarter of a cent per ton is realized. The tubes can be used until failure occurs without any risk of damage to the rayotube and replacement can be made quickly and conveniently. The tube finally fails by gradual weakening of the refractory at the metal-air interface due to progressive oxidation of the graphite.

10. The rayotube has also been experimented with for recording

molten iron temperatures in an intermittent tap cupola. This work was conducted on a laboratory basis at Battelle Memorial Institute for the Gray Iron Research Institute. In this application the instrument was installed in a well built on the front of the cupola at the tap hole, so that during a tap the metal flowed past the refractory tube. The thermometer-well was lined with refractory the same as the rest of the cupola well and the immersion tube was rammed into this extended breast, so that the end of the tube was just back of the curvature of lining. Figs. 5 and 6 show this construction. This type of installation gives an oscillating temperature record since the metal cools off somewhat as it collects in the well. The application of this method to a commercial cupola is now under development.

11. Through continued use of the rayotube it is possible to es-

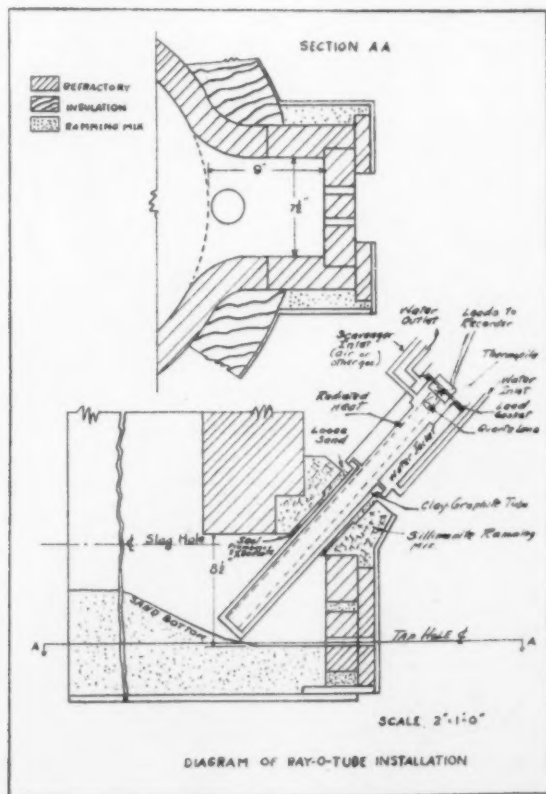


FIG. 5—INTERMITTENT TAP RAYOTUBE INSTALLATION.

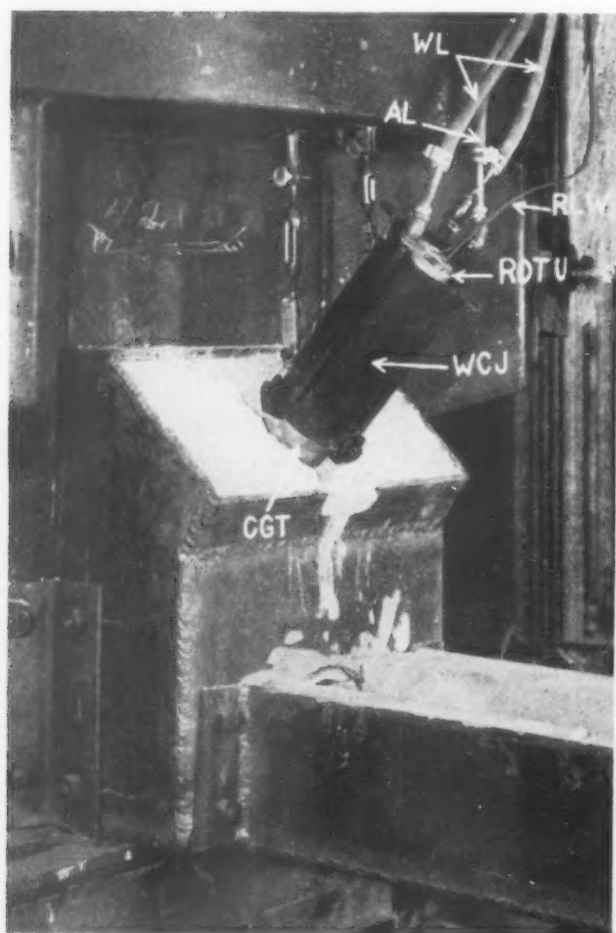


FIG. 6—RAYOTUBE IN OPENING POSITION: CGT-CLAY-GRAPHITE TUBE; WCJ-WATER COOLED JACKET; ROTU-RAYOTUBE UNIT; WL-WATER LINES; AL-AIR LINES; RLW-RECORDER LEAD WIRE.

tablish a more quantitative control over cupola operation. The main reaction taking place in the cupola results in the evolution of heat with its effect reflected in the temperature of iron melted. A study of the height of the coke bed, coke combustibility, blast volume and distribution, iron-coke ratio, size of coke splits, humidity of the blast, amount of refractory burnout, and carbon dioxide in the stack gases may be greatly facilitated by a continuous accurate record of the melting temperature. A section of a typical

temperature chart is shown by Fig. 7, which represents the type of record obtained. The effect of a number of these variables on metal temperature has been measured, but it is beyond the scope of this paper to discuss these relationships.

12. A portable rayotube, as shown in Fig. 8, is presently being developed for obtaining intermittent temperatures in ladles. The instrument is not water cooled, for the rayotube does not become heated appreciably during the 30-second period required for a reading. The air needed for scavenging the immersion tube is supplied by a small aspirating bulb held in the hand. The potential is read with a portable potentiometer, which is calibrated to read directly in degrees Fahrenheit. This portable instrument should

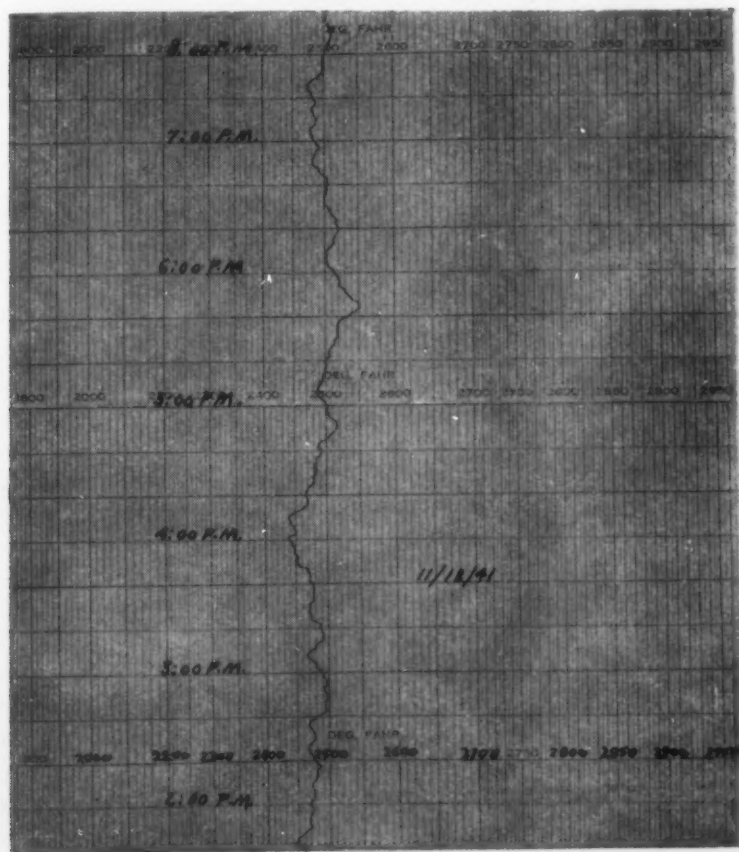


FIG. 7—TEMPERATURE RECORD OF RAYOTUBE INSTRUMENT IN FRONT SLAGGING WELL.



FIG. 8—PORTABLE RAYOTUBE IN USE.

prove very valuable in the foundry as a means of accurately determining ladle temperatures prior to casting. Its speed, ruggedness and constancy of calibration should make it particularly useful in both the foundry and the laboratory.

OPTICAL PYROMETER

13. Having available a reliable and accurate instrument such as the rayotube for evaluating true iron temperatures it is now possible to segregate the precision and accuracy aspects of the commonly used optical pyrometer.

14. The optical pyrometer functions upon the comparison of the brightness of a calibrated lamp filament with that of the body being measured. The type instrument used for this study was the

disappearing filament type. For a temperature determination the lamp filament is matched in brightness with that of the emitting surface by means of a rheostat that varies the electrical energy supplied to the lamp. This energy is calibrated to read directly in degrees of temperature.

15. The visible radiant energy upon which an optical pyrometer depends increases with temperature, but unfortunately, owing to certain changes in the ability of a molten iron surface to radiate energy, this rate of increase in radiation with temperature is not constant. It is an established fact that different hot bodies differ in their ability to radiate energy at the same temperature. A recognition of this has led to the concept of a "black body," that is, a body which at any given high temperature has maximum radiating or emissive ability. By definition, a black body can be duplicated by a space that is completely surrounded by uniformly heated walls. This black body condition, representing maximum emissivity at any temperature, has arbitrarily been given unit emissivity, which necessarily gives all bodies, other than this ideal black body, an emissivity of less than unity. It so happens that in the conventional use of an optical pyrometer the black body viewing conditions are only rarely realized and, hence, various emissivities are obtained depending on the viewing conditions (lack of equilibrium with surroundings), as well as the nature of the radiating surface.

16. In order to establish the suitability of the optical pyrometer for obtaining accurate molten iron temperature measurements, it was necessary to ascertain its precision as well as its accuracy. Precision, as defined by Sosman² is "the range in degrees within which several observers can read a temperature which is held perfectly constant, using identical apparatus, but with external conditions varying as widely as they ordinarily would in the customary use of such an instrument." The accuracy according to Sosman is usually less than the precision and is defined by him as "the range in degrees within which the same observers may be expected to agree with a temperature which is correct."

17. In this investigation the optical pyrometers used were the Leeds and Northrup direct reading potentiometer type with both "black body" and 0.4 emissivity calibration. In order to establish the precision of the optical pyrometer, for molten iron temperature,

² SOSMAN, R. B., "The Pyrometry of Solids and Surfaces," AMERICAN SOCIETY OF METALS Lectures—1938.

many hundred pairs of readings were taken simultaneously at various points in the plant, by two observers frequently interchanging instruments. The results of these comparisons at two points of observation in the plant are graphically represented in Fig. 9, which shows that no pair of readings deviated more than 35°F. from each other and that more than ninety per cent of all pairs of readings were less than 20°F. apart. This shows that the precision of the optical pyrometer for liquid iron is of a high enough order to warrant its use, provided its accuracy were also clearly established.

18. As has been shown, in order to determine the accuracy of the optical pyrometer, a reference instrument giving correct temperatures was necessary for comparison. For this purpose the rayotube was used and the point of comparison was the cupola runner where a large number of simultaneous readings with each type of instrument could be readily taken. It was at once found that there

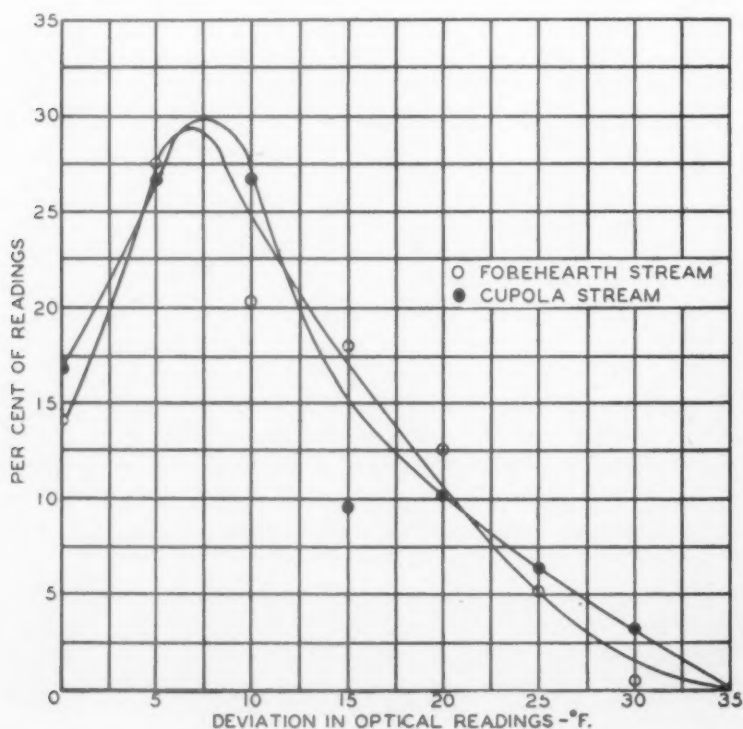


FIG. 9—OPTICAL PRECISION FREQUENCY CURVES.

was a large and variable divergence in temperature readings obtained by the two instruments. Certain pairs of measurements deviated as much as 120°F. , whereas some others agreed perfectly. Inasmuch as the optical pyrometer was used constantly on the 0.4 emissivity scale, this suggested that the actual emissivity of the molten iron surface being measured was changing erratically over wide limits. It also meant that when the temperature readings of the two instruments approximated each other, the true emissivity of the surface being measured was close to 0.4 and that when the optical pyrometer readings indicated a higher temperature, which invariably was the case when disagreements between the two instruments arose, the true emissivity increased and the larger the divergence, the more nearly this emissivity approached unity.

19. This being the state of affairs, it is obviously hopeless to determine the accuracy of an optical pyrometer until the emissivity of the surface being measured is known. This can be readily ascertained if the true temperature and the optical reading are both known. Fig. 10 is presented to offer one ready means for determining the true emissivity. There is shown a family of curves relating correct temperature with apparent temperature for various emissivities. This chart would be used as follows: Let us assume that the true temperature (as given by the rayotube) is 2475°F. , then assume that the optical pyrometer, using the 0.4 emissivity scale, gave a reading of 2575°F. Now if we drop a perpendicular from the intersection of 2575°F. true temperature on the 0.4 emissivity line to the horizontal true temperature line (2475°F.) we obtain the correct emissivity, which in this case would be 0.62. It is this real change in emissivity which has made the apparent reading at the arbitrary 0.4 emissivity calibration 100°F. too high.

20. It can be seen, therefore, that the accuracy of the optical pyrometer hinges on a knowledge of the true emissivity of the surfaces under measurement and as has been shown the latter cannot be ascertained unless the simultaneous correct temperature is known. Unfortunately, not many foundries are currently equipped with means for determining true temperature. This situation places severe restrictions on the fundamental suitability of the optical pyrometer as a means for obtaining reliable temperature measurements of molten cast iron. The only way out of this dilemma would be had if a molten iron surface varied in its emissivity characteristics with temperature according to certain regularity. In other words, if molten iron would change from a level of say 0.4

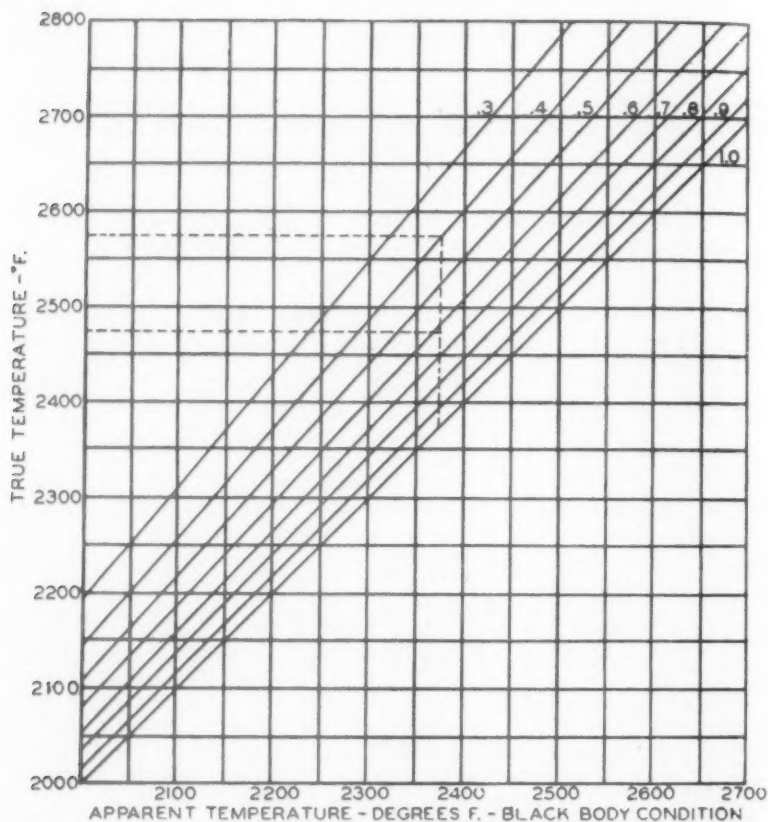


FIG. 10—EMISSIVITY CHART FOR OPTICAL PYROMETER (WAVE LENGTH 0.65 MICRON).

to other values at definite temperature levels, then proper, or at least approximate, temperature corrections could be applied. This possibility has been explored and was found to permit reasonable approximations to true temperature.

21. It was found, with the hypereutectic irons under examination, that at true temperatures above 2550°F. the emissivity consistently hovered about a mean value of 0.4, which of course signifies that if the optical pyrometer were used at this 0.4 scale, true temperatures within a limit of $\pm 20^\circ\text{F.}$ (limit of precision for optical pyrometer) would be regularly obtained. In the region between 2550°F. and 2500°F. the emissivity was found to fluctuate erratically between the limits of 0.4 and 0.7. This means that if the emissivity were 0.7 while the instrument were set on the 0.4 cali-

bration, a reading 125°F. too high would be reported. In the true temperature region below 2500°F., the emissivity was found to vary between the approximate limits of 0.55 and 0.75. It was found that the value of the average emissivity increased somewhat with reduction of temperature. The relationship between true emissivity and true temperature is shown in Fig. 10. This shows clearly that if the optical pyrometer is used only with the 0.4 emissivity calibration, errors on the high side as much as 150°F. would be reported in the lower temperature regions. If on the other hand the actual reading obtained were converted to a more probable mean emissivity, as indicated by the heavy line in Fig. 11, the probable error would be reduced to approximately $\pm 35^\circ\text{F}$. Owing to the variable nature of the emitting surfaces of the irons under observa-

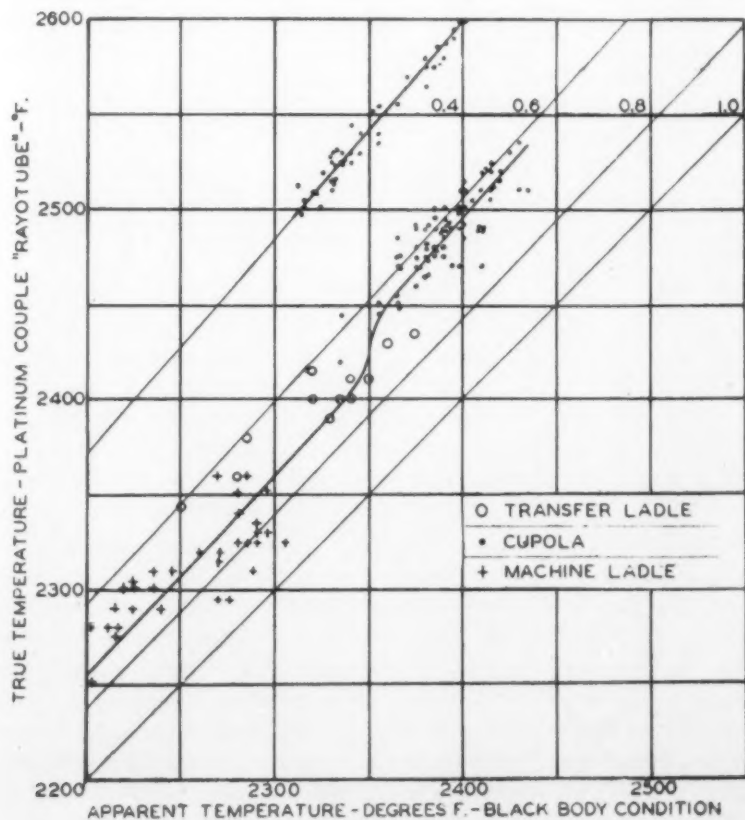


FIG. 11—EMISSIVITY VS. TEMPERATURE.



FIG. 12—MOLTEN IRON ISSUING FROM TILTING FOREHEARTH.

tion, this latter figure represents the limit for reliability of temperature readings obtainable in molten cast iron with an optical pyrometer at true temperatures below 2550°F .

22. These observations confirm those obtained by Wensel and Roeser³ who showed a similar sudden shift in emissivity at approximately 2500°F . The fact that the above authors obtained results agreeing with these, while investigating a large number of cast irons of different compositions, indicates that this phenomenon is of a general nature.

23. Many speculations as to the cause of this changing emission behavior have been proposed. In this study it was found that at true temperatures above 2550°F ., a flowing iron stream would show a glossy surface which through the ocular of the instrument exhibited a darkish green color. This surface invariably gave an emissivity of close to 0.4. In the temperature interval between 2550°F . and 2500°F ., a variegated surface would appear which was made up of a rapidly changing pattern of dark glossy metal and bright matte surfaces. Fig. 12 is a photograph, taken through suitable color filters, of this type of surface. It is obvious from this illustration why reported temperatures fluctuate so widely, because the surface pattern is continually changing at a fast rate and depends on the chance turbulence of the stream at any one instant. Below 2500°F ., the surface appearance would be continually on the bright matte side, varying somewhat in the degree of brightness as is suggested by the variation of emissivity indicated in Fig. 10. This variable surface condition has been ascribed to

³ Wensel, H. T., Roeser, W. F., "Temperature Measurement of Molten Cast Iron," TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION (1928), Vol. 36, pp. 191-212.

varying rates and degrees of oxidation of the metal surface. Additional mechanisms could probably be postulated but it is not intended at present to attempt a comprehensive explanation for the phenomenon. It has been shown that temperature readings, emissivities and the visual appearance of the molten surface are related in a logical and reproducible manner.

24. Considerable has been said regarding the accuracy and precision of temperature determinations obtained with optical pyrometers. From the standpoint of speed of response, ruggedness, economy, and general simplicity of technique, the optical pyrometer is undoubtedly well suited for its function. If its limitations on accuracy are recognized and due allowance made for them, the optical pyrometer is a satisfactory instrument for shop use.

SUMMARY

25. The rayotube, when sighted into a closed end immersion tube, has been shown suitable for the continuous measurement of the temperature of molten cast iron issuing from a cupola. The instrument is accurate, precise, rugged and cheap to operate. An adaptation of the rayotube for quick and intermittent temperature determinations of equal reliability is under development.

26. The optical pyrometer, when sighting on the free surface of molten iron, has certain limitations in accuracy due to changing emissivities of the molten iron surfaces. Methods are shown for minimizing these errors obtained with optical pyrometers.

DISCUSSION

Presiding: MAX KUNIANSKY, Lynchburg Foundry Co., Lynchburg, Va.

Co-Chairman: JOHN LOWE, Battelle Memorial Institute, Columbus, O.

DR. SCHUH: Since this paper was written, further work has been done to obtain molten iron temperatures in ladles and on open streams.

A black body immersion tube for the optical pyrometer has been designed to obtain true temperature readings in open ladles. (See Fig. 13.) The optical pyrometer is mounted at one end of a 3½ ft. length of steel tubing to which is fastened, at the other end, a small refractory tube for immersion. The refractory tube is immersed in the molten metal to sufficient depth to attain the temperature of metal in the same manner as the portable rayotube, with air being supplied by an aspirating bulb to clear the field of vision. The temperature of the bottom of the tube is read, using the black body calibration, after sufficient time has elapsed to bring the tube up to temperature. The time required is about 45 seconds.

This black body optical instrument is sufficiently accurate for cali-

brating work, as well as being suitable for regular shop use. The instrument was used as a means of calibrating the following described instrument which is a radiation instrument that reads temperature directly from the surface of a metal stream.

In a repetitive process, where molten iron is poured from a stationary ladle, it is possible to sight a radiation instrument on the metal stream and record the pouring temperature, providing the emissivity of that metal does not fluctuate excessively. This type of instrument, which is shown in Fig. 14, has been found suitable in our case since the metal is skimmed at the ladle lip while it is being poured, thereby assuring a clean, uniformly emissive metal. The consecutive casts are made at a rate of anywhere from 10 to 35 times per hour with each pour lasting for a period as short as 25 seconds. The electronic recorder is capable of recording these temperatures successfully. The usual galvanometer type recorder can also be used providing a high speed motor is installed and the zero stop for the slide wire movement is moved up sufficiently to reduce the distance required for the pen travel.

The radiation pyrometer is mounted with an open end tube sighting directly on the iron stream. Air is introduced at the lens and passed downward through the sighting tube and out the open end to remove gases and steam that would tend to collect on the lens.

A sample record, as obtained with the electronic recorder, mentioned above, is shown in Fig. 15. This record not only gives the actual pouring temperature of each cast, but also indicates the rate of casting. It is possible to correct for temperature fluctuations in the pouring temperature



FIG. 12—BLACK BODY IMMERSION TUBE FOR OPTICAL PYROMETER.

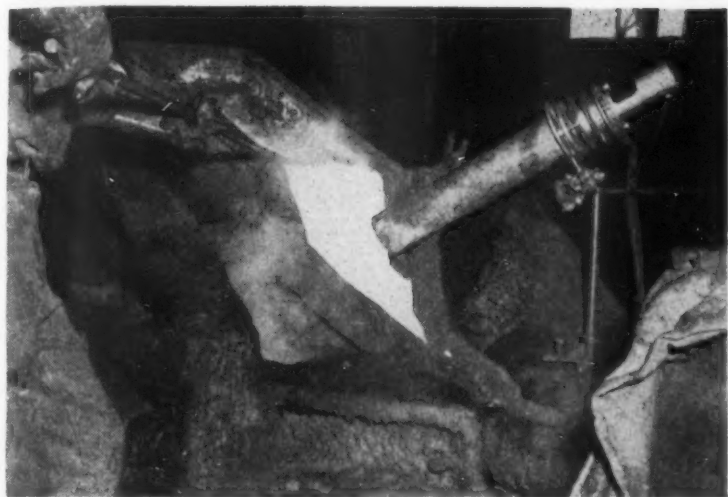


FIG. 14—RADIATION PYROMETER SIGHTED ON METAL STREAM.

by holding the metal in the transfer ladle for longer or shorter periods of time, whichever the case may be.

MEMBER: We have considerable difficulty in getting a clear surface on the stream below 2450°F. Would an emissivity of 0.65 give an approximately correct reading on the scale?

DR. SCHUH: We would estimate that with that condition, you would probably be correct within plus or minus 35°F. Twenty degrees of that error would be caused by the limit of precision of the optical pyrometer on such a surface while the remaining 15°F. would be caused by the actual varying emissivity, which is shown by the more scattered observations in the lower temperature range of Fig. 11. This scatter in readings is caused by a continually changing pattern between partial nascent metal and film covered metal.

In some ladles, especially if the lining is not thoroughly dry, a boiling effect takes place around the edge of the metal surface. This turbulence will cause the surface film to break and will leave a nascent metal surface about $\frac{1}{2}$ -in. in width at the edge of the metal surface. This surface can be used to read correct temperatures, as low as 2200°F. with the 0.4 scale. In most cases, however, temperatures are read on flowing streams, making it difficult to obtain nascent metal surfaces at low temperatures.

MEMBER: Have you made an attempt to investigate the influence of melting conditions with silicon content and alloy conditions on the emissivity?

DR. SCHUH: No, we have done nothing on that. There may be some compositional influence on the change in emissivity, but this has not been studied by us.

MEMBER: If this were used in a foundry where they cast different compositions, there might be a different emissivity for the film covered metal but the nascent metal would have the same emissivity.

DR. SCHUH: Wenzel and Roeser, in their work 14 years ago, covered quite a variety of compositions. They found that the composition had very little effect on the emissivity.

S. C. MASSARI¹: To date we have calibrated over 300 optical pyrometers and have invested approximately \$4,000 in equipment for calibrating them. We have made a good many observations in the foundry similar to those Dr. Schuh has made and what he has told you concurs within very narrow limits with our findings.

There are just a few things that I would like to point out that may be helpful. The foundryman is very familiar with the so-called breakers on iron in the ladle, which result from breaking of the oxide film due to turbulence of the metal, with consequent exposure of clean metal. This condition is most prevalent at the edge or close to the lining of the ladle. If a 0.40 emissivity is used for sighting on the clean metal in the

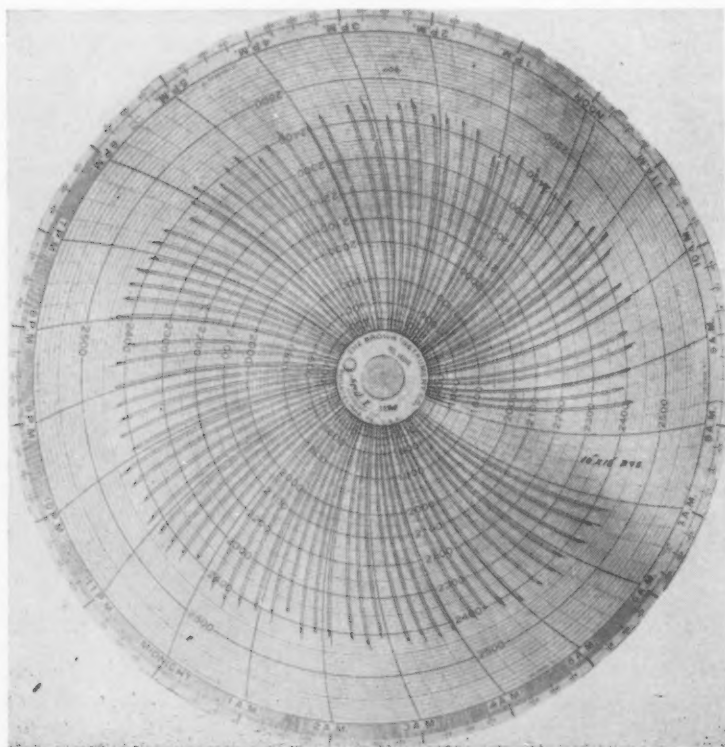


FIG. 15—TEMPERATURE RECORD OF MOLTEN IRON STREAM.

¹ Association of Manufacturers of Chilled Car Wheels, Chicago, Ill.

breakers, the observation with an optical pyrometer will be accurate within 20° or 25° of a true temperature.

The next point I wanted to bring out is that during the course of our measurements we likewise used a platinum vs. platinum-rhodium thermocouple. With such a thermocouple, gaseous contamination becomes a real problem and even though the thermocouple is very accurate to begin with, after a relatively few readings the gas liberated from the clay-graphite primary protection tube passes through the secondary tube and reacts with the thermocouple, destroying its calibration. Since these couples are quite expensive this is a serious condition.

We, however, conceived of the possibility of using a chromel-alumel thermocouple, which normally is not expected to be used at temperatures of molten metal. We found that for the matter of a few immersions, it was possible to use such a thermocouple protected by a graphite tube, and obtain temperature measurements which were very accurate.

DR. SCHUH: How high can you go?

MR. MASSARI: We measured temperatures as high as 2500°F.

MEMBER: Did you use the secondary, too?

MR. MASSARI: We used them both ways but we found very little advantage with the secondary tube. The length of time necessary for equilibrium to be attained when using a secondary tube was disadvantageous since the metal had to be held in the ladle too long. Ultimately we simply used a small graphite electrode about 1¼-in. in diameter drilled to accommodate the thermocouple directly.

M. J. BRADLEY²: Dr. Schuh has discussed conditions affecting the measurement of molten metal temperatures at the cupola and in the ladle. He has emphasized the importance of using the rayotube and the optical pyrometer under the conditions for which they have been calibrated—namely, black body conditions. He has demonstrated that correct measurements can be obtained with either the rayotube or the optical pyrometer. He has shown also that if these instruments are used to measure temperatures of molten metal in the open or not under black body conditions (as for example the molten metal in the cupola spout, fore-hearth, or ladle), certain precautions have to be taken and emissivity corrections have to be taken into account below certain temperature ranges if true temperatures are to be obtained. It is important that the operator understand fully these requirements, or limitations if you prefer, otherwise the temperatures reported may be considerably in error.

It is the usual practice in open-hearth shops when taking temperatures of the molten steel in the tapping spout to sight the optical pyrometer on the darker rather than on the lighter streaks in the metal stream. The compensation screen (emissivity 0.4) is used which corrects the temperature reading into terms of true temperature for this emissivity range. The temperatures being measured are usually around 2900°F. and the 0.4 emissivity correction seems to give consistent results. However, it is possible that this factor may not be correct for

² Leeds & Northrup Co., Philadelphia, Pa.

alloy heats. There is a feeling that different emissivity corrections should be made for different alloy heats. Just what these corrections should be, we are not prepared to say. Much more study is desirable in order to solve this problem.

I am sure that the information given by Dr. Schuh will assist in working out a standard technique of measuring temperatures of the molten metal in the foundry. Once the practice and methods are standardized, the temperatures measured in one foundry should be comparable to similar temperatures measured under similar conditions in any other foundry. I wish to compliment Dr. Schuh on his paper and the excellent manner in which it was presented.

The Use of the Hot Strength Test as a Tool for Controlling Core Mixtures[†]

BY FRED B. RIGGAN*, EAST ST. LOUIS, ILL.

Abstract

The author has used the hot strength test to improve the collapsing properties of the cores used in steel castings manufactured by his company. This paper shows the relative effects of silica flour and iron oxide, both on the hot strengths of core mixtures and their expansion and contraction. It is interesting to note that by means of the hot strength test, the author was able to eliminate the formation of a scab on his castings at a location adjacent to the gate.

1. A preliminary report showing results of some work done at The Key Co. foundry on the core mixtures, including the use of the hot strength testing machine, was submitted to the Subcommittee 6b7 on Physical Properties of Steel Foundry Sands at Elevated Temperatures of the A. F. A. Foundry Sand Research Committee. Later, this report was published.¹ Much of the material has been incorporated in the present paper with later data along this same line.

2. Our use of crude sand (that is, sand not washed and dried) for cores was discontinued due to the difficulty of buying on sufficiently uniform A. F. A. grain size and grain distribution tolerances. It was not economical to buy crude sand or set up to dry it. As a consequence, we would get an extreme variation in moisture content of the new sand as it arrived at the plant. Another bad feature in the use of crude sand was that it would freeze in the win-

[†] In the absence of the author, this paper was presented by R. H. Jacoby, Key Co., E. St. Louis, Ill.

* Metallurgist, The Key Co.

¹ Riggan, F. B., "Core Mixtures Controlled by Hot Strength Test," THE FOUNDRY, vol. 69, no. 11, November 1941, pp. 61, 151-153.

NOTE: This paper was presented at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

Table 1
SAND SPECIFICATION FOR OTTAWA SILICA SAND

Sieve No.	Desired Percentage Retained on Screen	Minimum* Percentage Limit on Screen	Maximum* Percentage Limit on Screen
40	2.0	....	3.0
50	34.0	30.0	45.0
70	46.0	35.0	50.0
100	15.0	12.0	20.0
140	3.0	2.0	4.7
200	....	....	0.7

ter and could not be moved into the hoppers without great difficulty.

3. A sand specification covering both A. F. A. grain size and distribution limits was accepted by certain of the producers and is in operation at this time. A variation of A. F. A. grain size of from 48 to 52 can cause a variation in permeability of our sand of 30 per cent if no regard is given to the distribution curve. Data on the specification are presented in Fig. 1 and Table 1.

4. The cores were baked in an elevator type continuous oven at 515°F. with an overall 2½ hour cycle. This was not a satisfactory

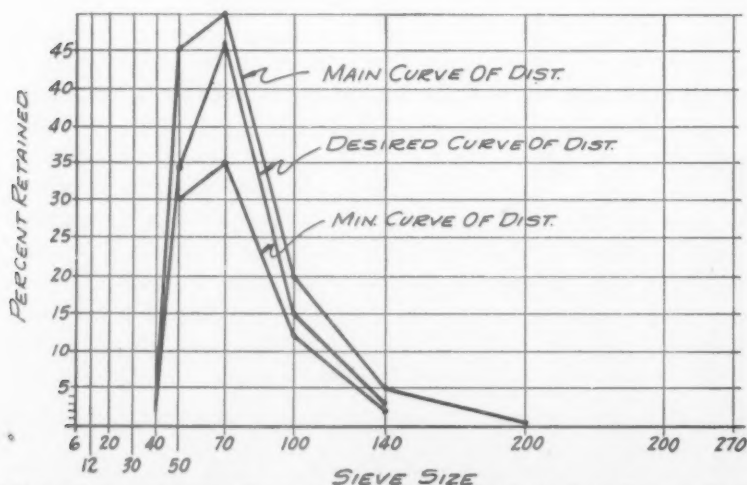


FIG. 1—GRAIN DISTRIBUTION CURVE OF WASHED AND DRIED SILICA SAND USED FOR CORES.

* The percentage remaining on screens may vary within the limits of the minimum and maximum values shown so long as the composite sand remains within range of AFA fineness No. 48 to 52 inclusive.

procedure for several reasons: The large cores did not seem to do much better the second trip around the oven than they did the first trip. Tensile cores added into the center of larger cores would take a ridiculously long time to bake. Those with appreciable amounts of silica flour would not bake to the center regardless of the number of cycles.

5. To stop the practice of sending large cores through the oven the second time, we experimented with faster drying binders. It was found that, with a certain resin core, the largest cores were perfectly dried with one pass through the core oven at a baking temperature of 450°F. and a 2 hour and 28-min. cycle. This lowered temperature prevented the smallest cores from over baking.

6. It was evident at the beginning of the resin core experiment that no single core mixture would do for all classes of work. Either the light walled castings would crack or the heavy walled castings would scab or cut. In this connection, it might be of interest to mention one very serious difficulty that we were able to eliminate by use of our new high temperature sand dilatometer. Certain castings were being scrapped due to a scab at the location adjacent to the gate.

7. Different core mixtures were tried to overcome this difficulty. More silica flour and more bond were added without curing the trouble. In fact, the core would crack the casting and yet the trouble persisted. After installing the dilatometer, it was found that the cores were too hard and that the expansion was so high that what we thought was a scab was in reality a buckle. The first metal through the gate against the core would cause the outer layer of the core to expand and buckle away. With this harder layer removed the relatively softer inner core would cut away and a typical scabbing action would take place during the pouring of the latter part of the metal entering the mold.

8. We standardized on three core mixtures for our entire range of work. No. 1 Core mixture for small diameter cores—thin sections, is comprised of 1000 lb. washed and dried Ottawa silica A. F. A. Fineness No. 50; 10 lb. silica flour; 6 qt. cereal binder; 3 qt. bentonite; 16 qt. resin, and 4 qt. core oil. The core oil was retained in small cores to prevent over baking and prevent sticking in core boxes.

9. No. 2 Core mixture, for cores having heavy wall thickness,

contains 1000 lb. washed and dried Ottawa silica A. F. A. Fineness No. 50; 50 lb. silica flour; 6 qt. cereal binder; 4 qt. bentonite; 16 qt. resin; 2 qt. fuel oil, and 4 qt. iron oxide.

Table 2

PHYSICAL PROPERTIES OF CORE MIXTURES

No.	Green Perm.	Dry Perm.	Green Comp., lb.	Deformation, 0.001-in.	Moisture, Per Cent	Tensile, lb. per sq. in.	Hardness	Hot Str. at 2500°F., lb.
1	150	210	2.5	30	3.0	90	60	4
2	120	160	2.2	28	4.0	100	66	22
3	135	200	2.0	40	3.3	98	64	12

10. No. 3 Core mixture, for large diameter cores—thin wall, is composed of 1000 lb. washed and dried silica A. F. A. Fineness



FIG. 2—DILATOMETER FURNACE IN OPERATION.

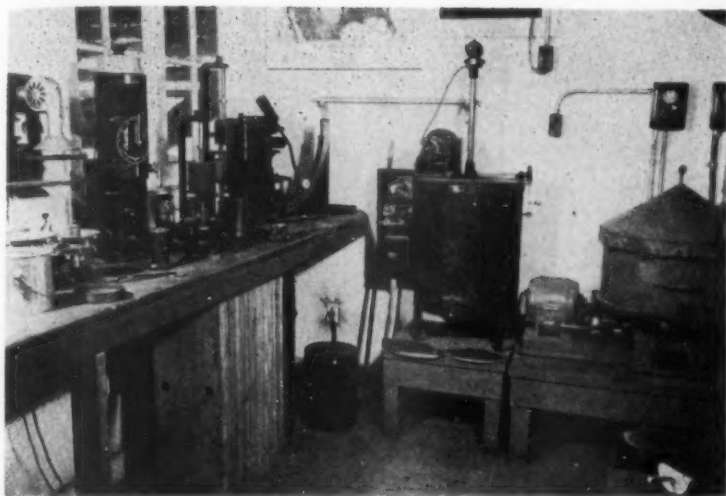


FIG. 3.—VIEW OF SAND RESEARCH AND TESTING LABORATORY.

No. 50; 25 lb. silica flour; 6 qt. cereal binder; 3 qt. bentonite; 20 qt. resin, and 2 qt. fuel oil.

11. These cores gave the properties shown in Table 2. The hot strength was measured on the $1\frac{1}{8}$ -in. x 2-in. specimen held at 2500°F. for 20 min. Baking cycle for the cores in Table 2 was 450°F. for a 2 hour and 28 min. cycle.

12. Iron oxide (Fe_2O_3), about 200 mesh, was added to the No. 2 core mixture to prevent burning-in on the inside of the casting where sharp corners or abrupt changes occurred due to change in section or other causes. This caused a great improvement in cleaning cost.

13. The hot strengths were about right for the various core diameters and metal thicknesses, so we adopted the practice of tagging the core mixture number into the core boxes so that the proper core sand would be rammed into the proper core box and also the casting would have the cast number of the core mixture on its inside surface. In this way we could work backward from the scrap heap in analyzing defects due to core failure.

14. Later experiments with the dilatometer developed the interesting fact that we could use a weak core suitable for our small work, say 3 to 5 lb. hot strength and, by the addition of iron oxide, obtain hot strengths as desired up to 20 lb. These strengths were

obtained by lowering the furnace, which is held at a temperature of 2500°F. over the specimens. After a 20 min. soak, a load is applied gradually until the sample breaks in compression. Figure 2 shows the furnace in operation while Fig. 3 shows a view of the sand testing laboratory at the Key Co. plant.

15. We reduced the silica flour in our No. 3 core to 15 lb. or 1½ per cent and obtained a 3 to 5 lb. hot strength. We added 1 per cent iron oxide to this same mixture and obtained 8 to 15 lb. hot strength. We added 2 per cent iron oxide which resulted in 23 to 50 lb. hot strength. This strength is sufficient to prevent cutting or washing on our largest work and gives a minimum of veining or penetration. One or two exceptional jobs, having small core diameter and very heavy section, require additional silica flour to prevent burning-in.

16. Test results on core sand mixtures given in Table 3 are taken from regular 1000 lb. batches. All batches have the same mixture containing 1000 lb. washed and dried Ottawa silica A. F. A.

Table 3
EFFECT OF OXIDE ADDITIONS ON HOT STRENGTH

Oxide, Per Cent	Green Perm.	Dry Perm.	Green Comp., lb.	Deformation, 0.001-in.	Moisture, Per Cent	Tensile, lb. per sq. in.	Hard- ness	Hot Str. at 2500°F., lb.
None	150	220	2.3	29	2.8	105	65	3
	150	220	2.5	23	2.9	100	60	3
	150	230	2.1	22	3.1	100	65	5
	150	220	2.2	35	3.0	100	65	5.5
	155	230	2.2	27	3.0	115	65	4
	165	220	1.6	35	3.0	105	65	4
	160	220	2.0	29	3.0	100	65	5
	155	220	2.4	30	2.9	115	62	5
	150	220	2.3	35	3.0	110	68	4
	155	220	2.2	33	3.0	105	65	4
	160	220	2.0	32	3.2	110	68	3.5
	160	220	2.0	33	3.0	115	69	5
	170	230	1.9	28	2.8	105	68	6.75
	170	240	1.4	34	3.0	100	68	5
	160	230	2.0	25	2.8	100	65	6
	170	220	2.2	29	2.8	105	65	3
1	150	220	2.3	29	3.1	100	63	10
	155	220	2.4	30	3.0	85	66	10
	155	220	2.4	28	2.8	100	65	9
	155	210	2.8	29	3.0	85	65	8.5
	155	215	2.5	24	3.0	95	65	13.5
	155	210	2.2	26	3.0	95	67	10.5
	150	210	2.3	36	3.4	110	68	15
	160	220	2.6	33	2.8	120	70	11
	155	220	2.0	30	2.9	90	70	15
	160	215	2.1	35	3.0	95	65	12
2	150	195	2.4	32	3.0	90	67	55
	155	205	1.9	31	2.7	100	63	35
	150	210	3.0	34	2.8	100	65	23
	150	210	2.5	36	2.9	105	68	25
	150	210	2.6	32	3.0	110	68	30
	150	200	3.5	22	3.0	95	63	28

Table 4

EFFECT OF INCREASING AMOUNTS OF IRON OXIDE

Core Mixture Used

1000 lb. Washed and Dried Ottawa A. F. A. Fineness No. 50
 15 lb. Silica Flour
 4 qt. Bentonite
 6 qt. Cereal Binder
 20 qt. Resin
 2 qt. Fuel Oil

Iron Oxide Additions, Per cent	Mois- ture, Per cent	Green Perm.	Green Compr., lb. per sq. in.	Def., in. per in.	Ten- sile Str., lb. per sq. in.	Hard- ness	Hot Str. at 2500°F., lb.	Hot Def., in. per in.
None	2.8	160	2.5	0.027	120	62	4	0.010
1	2.9	165	2.7	0.033	116	65	17	0.011
2	3.1	160	2.6	0.025	102	63	32	0.014
3	3.1	155	3.5	0.027	93	62	71	0.015
4	3.1	150	4.0	0.027	85	60	112	0.016
5	3.1	145	4.0	0.026	77	68	200	0.017

Fineness No. 48 to 52; 15 lb. silica flour; 4 qt. bentonite; 6 qt. cereal binder; 20 qt. resin; 2 qt. fuel oil and iron oxide (Fe_2O_3) as noted. Each test result is on a separate batch of core sand.

17. The idea of controlling core mixtures entirely by hot strength test seems to prove out in practice and the unexpected discovery that these hot strengths could be obtained solely by the addition of iron oxide was of great interest to us. Although 20 lb. hot strength at 2500°F. seemed to be strong enough to make any casting that we would be called upon to make, we ran a series of tests carrying the oxide addition on up to higher percentages. The data are presented in Table 4.

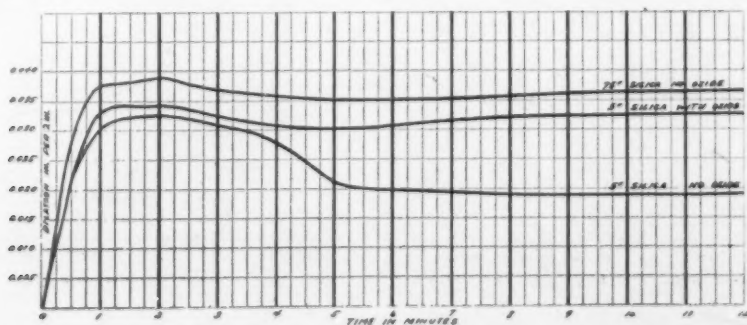


FIG. 4—EXPANSION AND CONTRACTION OF REGULAR CORE SAND MIXTURE WITH VARIOUS PERCENTAGES OF SILICA FLOUR.

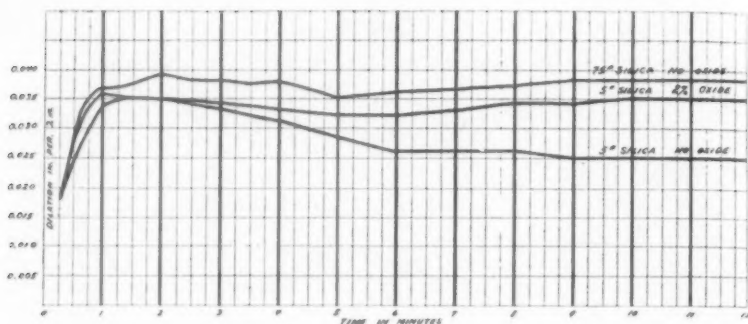


FIG. 5—EXPANSION AND CONTRACTION CORE SAND MIXTURE USING A. F. A. STANDARD TESTING SAND WITH VARIOUS ADDITIONS OF SILICA FLOUR AND IRON OXIDE.

18. A test was then run to compare the expansion and contraction characteristics of the cores having the hot strength raised by means of the iron oxide as against those of equal hot strength, attained by use of silica flour, using our regular core mixture as a base.

19. Our regular mixture (1000 lb. batch) with 5 lb. (or $\frac{1}{2}$ of 1 per cent) silica flour gave a hot strength of 2 lb. at 2500°F. With an addition of 2 per cent iron oxide, we obtained a 20 lb. hot strength. The regular 1000 lb. batch of core sand with a 75 lb. (or $7\frac{1}{2}$ per cent) silica flour addition, gave a 20 lb. hot strength. Figures 4 and 5 and Table 5 show the expansion and contraction characteristics of these mixtures.

20. The same experiment was run on small laboratory batches using a standard A. F. A. sand having all the grains through the 40 sieve, 95 per cent through the 50 sieve, the remainder on the 70 and 100 mesh with none through the 100 mesh sieves. This sand has an A. F. A. Fineness No. of 50 plus or minus 1.

Table 5

EFFECT OF INCREASING AMOUNTS OF IRON OXIDE BATCHES HAVING DIFFERENT AMOUNTS OF SILICA FLOUR ON HOT STRENGTH AT 2500°F.

Oxide, per cent	Hot Strength, lb.		
	(1.5 per cent) 15 lb. Silica Flour	25 lb. Silica Flour (2.5 per cent)	75 lb. Silica Flour (7.5 per cent)
None	3	5	20
1	12	15	55
2	20	28	120

21. The expansion and contraction characteristics of the two sands are similar, with the exception of the first minute or two of the mixtures having no silica flour or oxide additions.

22. The above full size tests were made on our regular washed and dried core sand meeting our distribution set-up as shown at the beginning of this paper.

23. We have been cautioned that trouble might be encountered if we used oxide containing calcium or like impurities. For this reason, we are careful not to change our source of supply. Also we are checking into the possibility of obtaining this oxide from the same mine so as to cut down the chance of variable still further.

ACKNOWLEDGMENTS

24. The author wishes to express his appreciation to Dr. H. Ries, Ithaca, N. Y., for his constructive criticism, and to Robert Jacoby, metallurgical department, The Key Co., for the photographs.

DISCUSSION

Presiding: H. H. BLOSJO, Minneapolis Electric Steel Castings Co., Minneapolis, Minn.

H. W. DIETERT (*written discussion*)¹: When iron oxide is added to a core mixture, a stable iron silicate is formed at elevated temperatures. This iron silicate forms a good bond at pouring temperatures of ferrous metals which explains the increase of hot strength when iron oxide in limited quantities is added to a core mixture.

Now, as to the effect of iron oxide additions on the refractoriness of a core, one must first define how refractoriness of the core is to be measured. If the A.F.A. sintering test is used as an index, then the addition of iron oxide will increase the sintering temperature. This is partly due to the fact that the surface strength of the core is increased with iron oxide. When the cone fusion test is used as the index of refractoriness, one may expect a decrease in cone fusion with an addition of iron oxide.

The sintering test has proven a very practical test for determining the refractoriness of molding materials. It reproduces the conditions found in a mold much more closely than a cone fusion test.

H. J. WENDT (*written discussion*)²: In a reprint taken from THE FOUNDRY, September, October, and November, 1941, F. B. Riggan, as co-author, stated that it was at Mr. Dietert's suggestion that iron oxide was added to a core mixture to prevent burning in on the inside of the casting where sharp corners or abrupt changes occurred. He found that this caused a great improvement in cleaning cost and that higher hot strengths could be obtained solely by the addition of iron oxide. How-

¹ Harry W. Dietert Co., Detroit, Mich.

² Rundle Manufacturing Co., Milwaukee, Wis.

ever, nothing was said about refractory value here. In the paper under discussion, the author states that the addition of iron oxide increases the refractory value of the core mixture.

In the book* by Mr. Dietert, he definitely stated that the iron oxide addition to a core mixture acted as a flux and lowered the refractory value.

Actual experiment for Rundle Manufacturing Company at Massachusetts Institute of Technology by Professor F. H. Norton showed a molding sand (heap) to have a vitrifying temperature of 2450°F. before removal of iron oxide, and a vitrifying temperature of 2700°F. after removal.

To quote from Prof. Norton's report, "From the phase rule diagram of FeO-SiO_2 one finds the eutectic melts at about 2150°F. In fact, at any percentage of the two components there will be some glass formation above 2210°F. The percentage of this formation, of course, will vary considerably."

What probably results in the case of an iron oxide addition to a core mixture is that the $\text{Fe}_2\text{O}_3\text{-SiO}_2$ eutectic is sufficiently low in refractory value and in the nature of a glaze is compressed as such on a flat plane just beneath the interface core surface by the load of the molten metal, thus lowering hot permeability sufficiently to retard penetration of the metal. Since the oxide has acted as a flux, the expansion coefficient of the mixture has been lowered, the tendency to buckle is decreased, and hot strength increases as a result of the glaze.

MEMBER: Is this iron oxide introduced as a powder?

MR. JACOBY: Yes, 200 mesh.

MEMBER: Has any attempt been made to use ferric chloride or some liquid form of iron which can be dissolved?

MR. JACOBY: No.

CHAIRMAN BLOSJO: Ferric chloride, on baking, would revert to ferric oxide at those temperatures. Has anyone had any experience with it?

MEMBER: We have a core about 4 ft. long and 6- to 8-in. in diameter and when it is cast and cooled, it has to be burned out with carbon. The rods and everything in it fuse. We use sand which contains about 85 per cent silica flour and still it fuses. Would the oxide help?

MR. JACOBY: Judging from our experience, it would not help. So far as we know, silica flour would be the best thing for that application.

MEMBER: I think the trouble in your case is that the core is improperly strengthened and dried.

MEMBER: We dry the core overnight for 3 days, put it in, let cool, and put it back in again. We tried drying them for 2 days and then changed back to 3 days. We use a regular rod vent, because the steel sometimes comes through if the rod vent is too big.

CHAIRMAN BLOSJO: What is the permeability of the core?

MEMBER: It runs about seven.

MEMBER: I agree that the core is not sufficiently dry and believe the addition of iron oxide would help although I do not guarantee that it will

* MODERN CORE PRACTICES AND THEORIES, Published by American Foundrymen's Association (1942).

eliminate all of the trouble. I believe it would be better if the core was dried without letting it cool, because the moisture content of the core mixture, as it is originally placed in the oven, is such that the core is much harder to dry if it is taken out of the oven and then replaced. It would be better to dry the core for 3 days in the oven than to put it in three times. It is much harder to heat a core the second time than it is the first time.

MR. WENDT: The iron oxide causes higher hot strength. Massachusetts Institute of Technology has done some work on iron oxide and they have found that a few tenths of a per cent would materially lessen the sintering point of the sand mixture. It seems to tend toward a glaze, and for that reason sets up its own hot strength. The oxide seems to form a eutectic with the sand.

MR. JACOBY: We do not know a lot about the technical aspects of the reaction. At the completion of high temperature tests, there is a glazed appearance in the form of a cone over each part of the testing member as stressed in compression, although the center part does not seem to have it.

MEMBER: What causes the veins when an iron oxide is not used? Is it the expansion of the core center? How does the metal get in to cause the veins if the core does not expand? Does the iron oxide take care of that expansion?

MR. JACOBY: It seems to have a fluxing action.

MEMBER: It seems that it counteracts the expansion of the core, causes the metal to open up and causes those veins.

MEMBER: I believe that iron oxide somewhat tends to take the place of silica flour in increasing the refractoriness of the core. It closes it up and does not let it be so permeable to the metal. I believe it does flux and form a eutectic on the skin of the core, holding the sand grains in place and cushioning the expansion very much as clay does, because if it changes form or becomes liquid, it undoubtedly has a cushioning effect. Perhaps that is what helps to eliminate the seaming.

CHAIRMAN BLOSJO: Iron oxide is one of the most dangerous things with which molten steel can come in contact. Why is it we can pour molten steel against iron oxide in the core?

MR. JACOBY: We do not know, but we do know that it works in practice because we have used it for some time.

J. A. DUMA³: Is there any likelihood of iron silicate forming when holding the specimen at the high temperature of 2500°F. for 12 min.? The formation of iron silicate would explain the fluxing action noted. When in contact with running metal, does the flux leave the core and tend to be washed to the surface? We had a similar experience when we used cement molds. Our objection to the cement was that it formed a flux on the surface of the metal which sometimes adhered to the walls of the mold and caused scabs to form.

MR. JACOBY: I believe that we might clarify the discussion somewhat, although it just represents an opinion. I would like to include an excerpt

³ Norfolk Navy Yard, Portsmouth, Va.

from a letter from Mr. Dietert. He says, "Iron oxide increases the sintering points of sands from 50 to 100 P. F. No one knows or seems to know definitely the function of iron oxide, with the exception that it increases the life of a core at elevated temperatures. In other words, collapsing is retarded and the dry strength is slightly increased."

CHAIRMAN BLOSJO: We do not believe that iron oxide increases the sintering point.

MEMBER: I cannot see how iron oxide would have the effect that it does, unless it lowered the sintering point. In my opinion, iron oxide undoubtedly forms a skin around the core, cushioning the core and holding the sand in place. The author says that in early investigations they had cores that washed at the gate, but that after running some tests in the dilatometer they found it was spalls caused from expansion. Then they found that increasing the silica flour and increasing the bonds of the cores did not do any good; the casting still had the scab in front of the gate. If there was not some action caused by the iron oxide, other than merely increasing the hot strength of the core, why did it stop the scab? It does increase the hot strength of the core, yet, the same thing can be done with silica so far as hot strength is concerned.

MR. JACOBY: I agree with you entirely. What the other action is we do not know.

CHAIRMAN BLOSJO: One other thing in this paper that surprises me is the high dry or baked permeability of these cores. In our foundry, permeability in the neighborhood of 160 to 200 would be prohibitive. Does the author have anything to say about why their permeability is satisfactory?

MR. JACOBY: We have found, since using this equipment, that we can vary our permeability over a range of some 50 points or so, and we do not have any trouble. We do not pour only carbon steel castings; we pour up to as high as 18-8, 4 to 6 per cent chrome and half of one per cent molybdenum, chiefly, and have very little penetration.

MEMBER: I believe the author will also state that their cores are washed with the silica flour; therefore, that permeability is not available to the metal. The metal would normally penetrate a core such as that if it were not washed.

CHAIRMAN BLOSJO: That is true in our shop, too, but we do not find that alone will stop the metal from going into the core. It naturally helps, but even with exceptionally thick coatings the metal will go right through the coating and into the core, unless the core has a relatively low permeability. We do not run any cores over 100 permeability, and some as low as 40 permeability.

MEMBER: Do you use iron oxide?

CHAIRMAN BLOSJO: We have not found any particular advantage in it in our shop. We do not know why. Perhaps we are not using it correctly, but we believe we are using it according to the manufacturer's recommendation.

MEMBER: Do you cast heavier castings?

CHAIRMAN BLOSJO: I don't believe so. Our average castings weigh

26 to 28 lb. We notice it more on heavier castings, but even on relatively light castings we get penetration, if we get much over 100 permeability.

MR. RIGGAN (*author's closure*): The comments of the several members who discussed this paper have added much of interest to the subject of hot strength testing.

It seems that no one disagrees with the statement that iron oxide increases the hot strength of a core. The author, in reporting this discovery, included other data which indicated that cores having iron oxide in the mixture would stand up under certain conditions of service where formerly larger percentages of silica flour had been used. This substitution, in certain instances, corrected some cracking difficulties that had accompanied the use of silica flour.

Mr. Jacoby's answers to questions covering our experiences and conclusions in our work with the high temperature tests on cores are fully in accord with those of the writer.

Mr. Wendt, in his written discussion, made the statement, "In the preprint under discussion, the author states that the addition of iron oxide increases the refractory value of the core mixture." The author very carefully refrained from using this term anywhere in the article due to the fact that there seems to be a difference of opinion among foundrymen as to just what we mean by such terms as refractoriness, fusion, sintering point, fluxing, vitrifying, temperature glazing, welding, etc. when applied to sand mixtures.

In the discussion of this paper, the statement was made that iron oxide tends to take the place of silica flour in increasing the refractoriness of the core and this statement is supported in the new book by Mr. Dietert on page 412, under the heading "Effect on Refractoriness" as follows: "The refractoriness of a core sand is not reduced by an addition of red iron oxide. For example, the sintering temperature of a certain sand without Fe_2O_3 is 2900°F . and when 2 per cent Fe_2O_3 is added, the sintering temperature is raised to 2940°F ." Here, apparently, Mr. Dietert feels that sintering temperature is an indication of refractoriness. It seems most likely that much of the confusion on whether iron oxide raises or lowers the sintering point of sand mixtures could be settled if we were all sure that we had the same thing in mind when we use the term "sintering point."

The Subcommittee 6b7 on Physical Properties of Steel Foundry Sands at Elevated Temperatures of the A.F.A. Foundry Sand Research Committee would certainly do a good turn for foundrymen who are not ceramic engineers if they would define the terms mentioned above. Then when we have a certain core that stands up under certain severe conditions where other cores failed, we would be better able to measure the property that is responsible.

Messrs. Blosjo and Duma added comments to the discussion that will tend to create further investigation as to just what happens to the skin of the core containing iron oxide when the hot metal heats the surface of that core to high temperatures.

Cost Problems Created by the War Effort

By E. J. METZGER*, YOUNGSTOWN, OHIO

Abstract

In this paper the author relates some of the methods used in complying with federal regulations governing non-ferrous foundry operations, covering the effect of over-time wage laws on costs during capacity operations, the effort to offset the loss of skilled men to the Selective Service by mechanizing everything possible in the foundry, two methods available for accelerated depreciation, and a simple method for showing the exact available inventory each month which is absolutely necessary to obtain metal in dealing with the War Production Board.

1. In 1940, we were operating at about 60 per cent of capacity. This capacity was based on what we considered the three most normal years in our history—1925, 1926, 1927. This capacity compares with what was set up in the cost and estimating system for the Non-Ferrous Foundry Industry during N. R. A., in which the "normal" was defined as 60 per cent of the best consecutive 6 months, extending back a period of 10 years.

Burden Rates

2. Today we are operating at about 300 per cent of that capacity. Our burden rates have not decreased proportionately, due to increased operating and fixed cost, other than wages. Our burden rates are close to 90 per cent of 1940 averages. These burden rates are based on a span of 12 months of operation. To eliminate normal fluctuations from month to month, we arrive at the actual burden rates for the past month, then, by deducting the twelfth previous month and adding the immediate past month, we are able to maintain a 12-month running average. This provides a fairly sure figure with which to estimate.

Overtime

3. The overtime wages, a much debated question today, was no problem in 1940. Forty-four hours a week was law. We permitted no

* Falcon Bronze Co.

NOTE: This paper was presented at the Cost Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

exceptions, every man had to work within it. We worked a strict 5-day week. On Friday, we would post a list of men who were close to 44 hours. We scheduled the work so they could quit at the termination of the limit.

4. Today, as always, our job is to serve our customers. We do not permit the overtime restrictions to interfere.

5. We have removed from the foundry everything that occupied floor space and was not in constant use. We have improved our handling system for transporting materials and equipment to and from the molding floors. Consequently, we are manned to the limit of our floor space. The weekly hour limit is determined by the willingness and constitution of the men and varies between 48 and 60 hours.

Labor Costs

6. This practice has increased our hourly labor cost over the past 2 years in the various departments between 8 and 25 per cent, together with a general increase in wages of 16 per cent. The overall increase for the entire plant, allowing for general wage advances, amounts to only 3 per cent. This small increase in labor cost is probably due to the greater number of learners who, naturally, do not receive full journeymen rates.

Walsh-Healy Requirements

7. The war effort has made it necessary for us to accept direct government contracts, a practice we have never undertaken in the past. To comply with the Walsh-Healy Labor Act which must be strictly observed in this work, it is necessary to compute overtime and premium pay on a daily basis. In other words, overtime and excess compensation for premium begin after 8 hours in one day as well as 40 hours in one week. It has been the practice for many foundries to disregard daily overtime hours and compute overtime and excess compensation beginning at the termination of 40 hours in any one week. This practice is all right if it is possible to limit those men in your plant occupied on direct Federal contracts to a maximum of 8 hours per day.

8. The Walsh-Healy Labor Act also provides for definite restrictions on minimum wage rates based on those prevailing in the particular community. It might be well to review the details of this Act before proceeding with any direct Federal contracts.

Personnel

9. The Selective Service is becoming an increasing hardship. We do not have the space to train men beforehand to replace selectees. Therefore, when a man is drafted, we are compelled to replace him with a learner whose output is lower; consequently, we suffer a loss of plant output.

10. We always have preferred the strapping young fellows with mechanical aptitudes and a good mind for our work. The War is a game for youth. Industry must adjust itself to the loss of these men. Their dash, daring, and enthusiasm, so desirable to modern, up-to-the-minute competitive industry, will be lost for the duration. Their loss is a hard blow, but cannot be helped.

11. Our only hope for maintaining present production levels with older men and less experienced men, is to mechanize more with labor-saving equipment. Tremendous savings can be made with modern handling devices such as lift trucks, various types of mobile hoists, conveyors, etc., and by the elimination of confusion by routing material and products in an assembly line course on a one-way street.

Depreciation

12. Equipment as well as buildings can be purchased and financed and depreciated on the 5-year accelerated basis, by applying to the War Production Board for a "Certificate of Necessity." We have received two of these grants for expansion.

13. Another available method of writing off machinery, more rapid than the straight line method of depreciation, usually about 10 years, is known as the unit of production method for an accelerated period. In using this method, the life expectancy of the machine is set up as so many units. To illustrate: On a basis of a 5 or 6 day operation at 8 hours per day, the units produced or operations performed per day, multiplied by the number of days considered to be the normal life of the machine, is set up. Then accelerated depreciation is calculated on the basis of 24 hours per day or 168 hours per week operation. The amortization period of the machine may be reduced to a basis comparable to the issuance of a "Certificate of Necessity."

Inventory

14. The problem of obtaining metals today is acute. Allocations are made according to priorities, and, at times, present steel mak-

ing capacity seems threatened because of inadequate priority in favor of non-existent steel capacity, which is favored with high ratings. So far we have been fortunate, by dint of unrelenting effort and persuasion.

15. In the past, we carried a large inventory and, upon acceptance of new business, we covered immediately. Today this is impossible and, to show the exact metal inventory at the beginning of a month, we have found it necessary to alter our goods in process account. We have always had considerable stock items on hand listed on the books as raw metal; also certain castings that were poured, but still lacked considerable finishing operations, were accounted for as raw metal. This system made it difficult to show our exact requirements, when allocations were granted. We now show a "Goods in Process and Finished but Unshipped" castings account. These castings are accurately inventoried and priced according to their stage of completion.

16. It is a somewhat more involved system, but we know exactly how much raw metal we have available each month and also it enables us to anticipate our requirements accurately.

17. As this vast war effort continues to accelerate, there will be many more headaches for the cost man. We all hope that, when we sit back and review our present problems, they will not appear too simple in comparison.

Foundry Costs and the Defense Program†

BY S. KITTO*, RACINE, WIS.

1. The cowardly attack on "Pearl Harbor" has made us realize that we have a job to do—"To win this war above everything else, regardless of cost." This has presented many new problems to the accounting profession and has put every cost accounting system to its severest test.

2. The foundry industry was one of the first to answer the call of our government for increased production. It immediately made plans to equip itself so as to be in a position to produce the type of jobs required for defense. This meant a change from automotive castings, perhaps, to tank parts, implements to trucks, or, possibly, shells, gun mounts and carriages, etc.

3. Shortly after the War Production Program got under way, it became apparent that there would be need for additional steel castings over what could be produced on a 24 hour basis. A number of companies expanded their facilities to meet this demand. Such programs also called for the training of skilled man-power and payment of considerable overtime premiums.

4. Also, there have been frequent changes in labor rates, and commodity prices are changing constantly. Obviously, such changes would affect costs and the applications of variable and overhead burdens unless they were applied on a sound basis.

COST PROCEDURES MUST BE FLEXIBLE

5. The modern foundry recognized that doing a jobbing business may bring about just such conditions, and that their cost procedures would have to be sufficiently flexible to reflect the changes and produce a reasonably accurate cost; also, that certain inefficiencies were not directly chargeable to the customer. A standard cost system, based on a reasonable output, will reflect such variables.

6. We all recognize the importance of basing our costs on market values; therefore, a standard set-up must be in sufficient detail to enable the accounting department to revise unit costs to the changing markets. We also recognize that the more expense we can allocate directly to the job, the more accurate will be the results.

† In the absence of the author this paper was presented by R. L. Lee, Liberty Foundry Div., Grede Foundries, Inc., Wauwatosa, Wis.

* Belle City Malleable Iron Co.

7. The industry has recommended that the making of molds and pouring them, making the necessary cores, removing of gates, straightening, and any special operations, such as reaming, drilling, or machining, be considered a direct cost chargeable to specific jobs. This can now very well include special inspection, Brinelling, testing, and heat treating on jobs required to meet certain specifications.

8. Those expenses in the same departments that cannot be specifically allocated to the individual jobs, are considered as an indirect expense to be prorated in relationship to the direct costs. We then have those costs based on a uniform tonnage basis, such as cleaning and annealing.

ANALYSIS OF VARIABLES

9. The importance of keeping material costs, including metals as well, on a current market basis, already has been mentioned, so we will proceed to the analysis of variables and fixed charge expenses; *viz.*, supervision, watchmen, janitors, vacation expense, payroll taxes, power and light insurance, real and personal property taxes, and depreciation.

10. Our first task is to determine the pro rata share to each department on an equitable basis: such as supervision, janitors, vacation expense and payroll taxes on the basis of payroll; power and light on horsepower ratings; watchmen, insurance, real and personal taxes on values; finally, depreciation on the actual departmental depreciation based on the equipment and building rates and values, all based on a reasonable productive capacity of such a department.

11. Secondly, determine the productive unit in the department, such as tons of melt for the melting department, molding floor space in foundry, number of core-making hours in core room, grinding and straightening units in finish department, tons cleanable with cleaning equipment and annealing tonnage capacity. With the expense and units firmly established, we are able to arrive at a standard expense per productive unit.

EFFECT OF INCREASED PRODUCTION

12. All industries discovered that, when working hours were increased through longer working periods or additional employees, it was necessary to proportionately increase the supervisory force

by additions or extra compensation for longer hours. This is also true of janitors.

13. As payrolls increased, so did payroll taxes. Should the percentage for social security taxes be changed, the standard base should be changed likewise.

14. Vacations are based on employees' earnings for a stipulated time and, therefore, will be in direct relation to payrolls.

15. The fact that increased production has extended the time to periods, when lights are necessary, has offset the gains through reduction in rates because of increased volume. Power factors also have been penalized.

16. Watchmen service has been extended to properly safeguard plants and products. Real and personal taxes have not advanced with the extension of hours of productivity, but would in the case of any expansion of facilities.

17. The Internal Revenue Department has recognized that, with increased use of facilities, the rate of depreciation is accelerated and any unusual conversion in manufacturing products will bring about obsolescences.

18. So, we find that even those expenses that were ordinarily considered fixed in volume do increase or decrease with the units of production, and consequently become standards for a given unit.

PROPER COST UNITS MUST BE DETERMINED

19. What we have been trying to bring out is, that in any cost procedure, we must determine the proper units for each operation that definitely control the volume of production and cost. For example, melting costs would not be based on molding hours or tons of castings when the volume is controlled by the tons that can be melted. Likewise, straightening would be based on the equipment available and not the volume of castings produced.

20. The selling prices of steel and gray iron castings have been frozen as of certain dates. This means that foundries producing such castings must use the cost in effect at that time, and on new jobs the cost would be determined on the cost factors in effect at such time. It also may be desirable to determine current costs based on prevailing labor rates and material prices to know what is left as a profit in the job.

DISCUSSION

Presiding: R. L. LEE, Liberty Foundry Div., Grede Foundries, Inc., Wauwatosa, Wis.

CHAIRMAN LEE: In Mr. Kitto's paper, he spoke of keeping the costs in the cleaning room on a tonnage basis. I disagree with that.

C. W. MILLER¹: We split our costs in the cleaning department. We have found that we are able to use the tonnage basis very successfully on the wheelabrator, due to the fact that the type of castings going through are pretty much alike. We use the direct labor method on the table blast machine as well as in the sand blast room.

In these discussions, we have talked about costs alone. I think that pricing is just as much a problem of costing as the collecting of the expenses. The point that I would like to get into the discussion is as to what methods to use for pricing the casting after you have the cost. Just adding a percentage to the total does not seem to be quite satisfactory because there is such a wide variation in the amounts of labor and material in a certain casting. We find the variation of material cost of the casting will run from 20 per cent to about 60 or 65 per cent of the cost.

I think that pricing should be on a conversion basis rather than on the total cost basis. It is possible to make more money by turning over a higher tonnage.

CHAIRMAN LEE: The same thing is true with steel. In making stainless steel and getting from 50c to \$1.50 a pound, there is quite a difference when adding 10 per cent to the cost of metal, as compared with lower cost commercial steel.

MR. METZGER: We add our percentage before we add the metal.

CHAIRMAN LEE: We do that in our costing in our steel foundry, too.

MR. METZGER: We use alloys that cost up to 30c per lb., and we make a lot of castings from metals that are worth 10c per lb. The more expensive alloys usually present more casting difficulties. They generally require special heads and gates, or sometimes special sand. I think this also is true with steel alloys. The hazards are greater, the losses are higher and the specifications are usually more rigid. There undoubtedly is some justification for including metal before computing the profit percentage.

CHAIRMAN LEE: I do think there is much less variation in gray iron and malleable than there is in steel or non-ferrous.

Of course, one of the problems, in addition to whether the metal cost should be added after computing the percentage as far as gray iron is concerned, is that the temporary order said castings should be priced on the October basis or using the same method. In our gray iron foundries, we have gone so far as to assume that means adding a particular percentage on a particular customer's work, using the same percentage used in October.

D. OTTAWAY²: We do not price our malleable iron castings uniformly,

¹ Universal Foundry Co., Oshkosh, Wis.

² Erie Malleable Iron Co., Erie, Pa.

but quite often we price a job on the basis of the molder's production on that particular job. We use so much floor space and so much overhead of one kind or another. If we had our shop filled up with this particular job, and we wanted to make a certain amount in a year, how much would we have to apply per hundredweight to make that amount in a year? We base it on a floor space rather than on the percentage of sales.

CHAIRMAN LEE: That is a very good point because it is true that if the shop is filled with low-cost work, it would not be possible to make nearly as much money on the percentage of sales basis as on the small floor space basis.

I would like to mention the effect of using the weight of the core material on costs. It has been our experience that when the cost of the core is segregated, and applied on the core weight basis to the job, leaving the rest of the expenses to be apportioned on a percentage of direct labor, the problem is pretty well solved. On an intricate small core that is expensive to make, there is usually more supervision. More of all the other ordinary charges in the department must be applied to that particular core.

In a discussion we had two or three years ago, one of the gray iron men brought up a rather interesting point, namely, that the molding foreman figured by using the recovered core he could reduce the molding price either 40 or 50 cents. On investigation it was found that about 2,000 lb. of sand would have to be used in the core department, making a total cost of around \$5 that must be expended in the core department to save 40 or 50 cents in the molding department.

Another practice of the molding department in times of depression was to try to cut molding prices and still apply the regular molding overhead on the basis of the cut price. There is no way in which the amount of sand or other materials that go into the molds goes down with the cut in the molding prices. On the other hand, neither do they go up in proportion with an increase in rate.

E. T. RUNGE³: Several of the gray iron foundries keep the dry core material cost separate. As you know, that is made up of supplies, sand, oven fuel, etc., and will average close to a half cent per lb. or about 100 per cent of core productive labor, a part of the total 150 per cent overhead. Segregating and keeping the core material separate gives a more accurate cost. A little stock core weighing an ounce, in a casting, as against a 420 lb. casting taking 900 lb. of dry core material, presents quite a problem against another casting weighing 420 lbs., taking about 20 or 30 lb. of core. Instead of weighing all dry cores, a simple procedure is to weigh up the sand.

CHAIRMAN LEE: We have five core blowers in our core department working a full eight hours a day which brings up the problem of a reduced core cost and emphasizes more strongly the importance of the core material. Our average reduction in core costs has been about 40 per cent through the use of core blowers.

³E. T. Runge Cost Co., Cleveland, O.

MR. MILLER: The danger in anybody going into core blowing is that he will take the direct labor cost and then start to apply the same overhead as before. The result is that he is not getting all his costs because it costs a lot of money to run a core blower.

CHAIRMAN LEE: I would like to bring up the importance of using the yields in figuring the cost of melting. In one of our plants the difference between a 70 per cent yield and a 50 per cent yield is that the cost of metal for the 50 per cent yield is 124 per cent of the 70 per cent yield. Our 22 per cent yield is 201 per cent of the 70 per cent yield. By a 70 per cent yield, I mean that 100 lb. of metal is poured to get 70 lb. of castings. Fifty per cent yield is 100 lb. of metal for 50 lb. of castings, and a 22 per cent yield is 100 lb. of metal for 22 lb. of castings. In order to pour any one of those three castings, you should melt 100 pounds, and you get a lot more sprue and risers left from the 22-pound casting than you do from the 70. An average cost for metal will put a penalty on the high yield job and give away something on the low yield job. It does not make any difference whether it is gray iron or steel, non-ferrous or malleable, or the percentage relationship may not be just the same as the figures I have given, but there will be quite a difference between the high and low yield jobs.

Another important point, strictly from the standpoint of those who develop historical costs, is the development of false costs through the improper application of direct labor costs. A great many foundries use the molding price paid to the molder as the cost. At a molding cost of five cents a mold, 100 castings will show a five dollar mold cost, whereas if all pay roll expenditures are properly accounted for, the mold cost might be \$6.50 instead of \$5, because of scrap and allowances.

If \$5 is used as the mold cost and the average overhead burden in the molding department is 100 per cent, only \$5 has been recovered when, actually, \$6.50 was spent.

MR. OTTAWAY: Why would \$6.50 be spent on direct labor instead of \$5 if there is a piece-work price?

CHAIRMAN LEE: In practically every foundry there is cold or dirty iron once in a while, and there are other things of that sort that are really not the molder's fault.

MR. OTTAWAY: We pay for scrap which is not the fault of the molder.

W. J. WADSWORTH, JR.⁴: Could an account such as cost of reclamation or cost of errors be used to make an item like that stand out?

CHAIRMAN LEE: I thoroughly agree with you. Of course, that would come to what I would call a standard cost.

In that connection, when I was investigating the possibility of putting standard costs in our foundries, I went into one of the plants where a job was causing a little trouble. I made some tests, and found out that over a period of a year and a half, the extra labor on that one job amounted to \$51 a day, which was not included in the estimate. I am speaking about charging all labor costs to particular jobs. In the job I mentioned, the majority of the extra costs were in the cleaning de-

⁴ Foundry Div., R. Hoe & Co., Inc., Dunellen, N. J.

partment. We will say the casting went down the line to the grinder and a defect was discovered, making welding necessary. It went all the way down the cleaning line again and appeared to be okay. Then, we will say, it went to the water test, a leak was found, and it had to be welded again. Then it went all the way down the line, back to the water test again. If there is proper accounting for labor in the foundry, all of those extra operations will be charged to one particular job, and the records will show that \$51 has been spent, in this case, in extra labor on the job. Something like that would show under standard costs. Under standard costs it is not necessary to pay attention to a job that goes through exactly according to the estimate. It is the job that costs much more than the standard that is brought to attention. By the same token, in fairness to the customer, if a job is a great deal below the standard, it is not fair to charge the customer more than should be charged.

ARTHUR J. SMITKE¹: We have a labor variance report issued daily. Any job that varies from the standard rates is tabulated on the report and shows us what is happening on the job. We also list the time as applied to that job.

MEMBER: How do you determine the cost of a job?

CHAIRMAN LEE: Some time ago a friend in the foundry business said that jobs, supposed to be one-time jobs, often come back a year or two after being made the first time. We will say it took five hours to make the job the first time, and he paid the molder \$1 an hour, so he paid \$5.00 for molding, and he established his cost on that basis. A year later it took the molder 8 hours for the same job, and it cost him eight hours direct molding. No material changes in labor or metals had occurred, so he would have to charge the customer exactly the same as he did the first time.

I suggested that in a case like that where repeats occur he establish a piece-work price on the basis of the first time it was made. He started doing that, and the method is working satisfactorily.

MEMBER: How do you figure the piece work on the grinding wheels in the cleaning room?

CHAIRMAN LEE: We timed the job. If the job is timed properly it will be found that it takes a certain amount of time to grind a certain area and a certain thickness of metal from the casting, making allowance for the weight of the casting and other factors that enter into it. But all of those factors can be established and the grinding price set before the job goes into the shop.

MR. SMITKE: We are trying to establish a piece-work basis in our gray iron cleaning room. Would that affect the rate?

CHAIRMAN LEE: You would merely continue to pay on the tonnage basis. Begin to establish your piece-work costs, and when you are sure of them turn the whole thing over, and you can almost always show the men that they can earn more money than they did on the previous basis, because of more production.

¹ Novo Engine Co., Lansing, Mich.

MR. SMITKE: On the tonnage basis, the large heavy castings carry the small intricate castings.

MR. WADSWORTH: Regarding the piece-work operation in a heavy shop, where cores are set with jib cranes and overhead cranes and the flasks have to be moved, how would you control the lost time waiting for the cranes and flasks?

CHAIRMAN LEE: Our men would go to the crane man or to the flask man and tell him to take less time. Of course, in every piece-work price established, a certain amount of setup time must be allowed and there are cases where it is necessary to have a waiting time, under unavoidable conditions. A lot of those unavoidable conditions are not unavoidable, however, when the men really get interested and are anxious to make money.

MR. WADSWORTH: We have had a condition like that facing us and we have attempted to encourage the man on the piece-work basis. We have acknowledged the fact that we might have to wait for a crane and not be able to do anything about it, but regardless of the fact that it may have been allowed for in the time for the job when the price was set, they still decline.

CHAIRMAN LEE: In one of our foundries we still have the same number of cranes that we had six or seven years ago, and we are producing about 300 per cent of the castings that we were producing then. Our cranes were all busy at that time, and the men had to wait. We did not have piece work. The men have to wait a little while now, but they are getting out a lot more castings and not waiting as long as they did then.

J. H. HOCHMAN⁶: There are so many different variables which are hard to measure, such as storage, waiting for elevators, and other things which fall into that category, that it pays to be liberal because there is more to be gained through that procedure than by trying to cut the corners.

CHAIRMAN LEE: It will be more expensive at the start, but it will be cheaper in the long run after the men are educated to it.

MR. MILLER: We had a lot of complaints about waiting time and finally decided to pay for it. In many cases we found that it was not the man's fault but that it was poor supervision in the department. It was showing up the individual foreman as his report came out, and that made him work harder in order to eliminate it. Of course, in some cases it did involve equipment. We felt that rather than hide it in the direct cost, it would be better to pay for it and know where it is being paid.

We have established a complete piece-rate system throughout our cleaning and finishing department. In our grinding department all the rates are set before the job enters the shop. In fact, we use the same rate in estimating the job. All our grinding rates are built up on the basis of the size of the gate, the number of gates to be ground, the number of times the casting has to be turned and handled, and the weight of the casting. These are standard costs. We have been using the sys-

⁶ The Permold Co., Medina, O.

tem for about 4 years. It works out very satisfactorily and has practically eliminated all complaints on piece rates.

MR. OTTAWAY: How would you go about putting the hand straightening department of a malleable foundry on piece work? There is some inspection involved. We have tried it, but not very successfully. We have had to give it up, due to the fact that there is carelessness prevalent in the inspection function.

CHAIRMAN LEE: In two of our shops where the inspection is on a piece-work basis, if the castings are not properly inspected, they must be reinspected free of charge. That is a good way to get proper inspection on your castings.

MR. KITTO: (*author's closure*): In connection with the point brought up by Mr. Lee regarding cleaning costs on a tonnage basis, I had reference to the actual cleaning of castings, not including finishing such as grinding, chipping, etc. I am quite in accord with Mr. Miller that if it is possible to keep these individual pattern numbers so that they may be charged directly to the job it would be preferable to have it as direct. I doubt whether this is practical for all cleaning purposes, and it has been generally accepted that tonnage is the more practical method.

I also note that Mr. Miller raised some question regarding pricing on the basis of costs. I have always felt that if proper standard costs are set up so as to include standards for materials, as well as labor, according to the operations necessary on castings, such a cost will reflect the condition in the plant with regard to production, floor space, or investment, and, therefore, costs can be used for a basis of pricing. This is further brought out by the fact that no definite policy is established with regard to payment of molding prices or any direct costs, and, therefore, no accurate rates for absorbing overhead expenses can be accurately established.

Mr. Lee mentioned establishing piece-work prices on the basis of past performance. I believe that we all recognize the differences in human element with regard to production, and such a method should not be used in establishing standard costs, as the variances depend entirely on an individual rather than on a definite company policy.

Making Steel in the Basic Electric Furnace for Navy Castings†

By S. W. BRINSON* and F. B. ANDERSON*, PORTSMOUTH, VA.

Abstract

This paper deals with the making of steel for castings at the Norfolk Navy Yard and describes the melting equipment used, together with some information on the use of the furnaces for metals other than steel. The writers first take up the development of steel making capacity at the Navy Yard, describing experiences, first, with the side-blow converter, and later with the various furnaces for basic electric steel melting. Furnaces discussed are 500 lb., 1000 lb. and 3-ton top-charged electric. Types of steel made are reported as plain, hard, nickel-chromium, carbon-molybdenum, ordnance, manganese and corrosion resistant. Other alloys melted are monel metal and silicon monel. The refractory practice is discussed in detail, comparing the operation for the 1000 lb. and 3-ton furnaces. While the Norfolk Navy Yard practice has been termed "unorthodox," the methods followed produce the best results as indicated by tables giving physical tests for different types of castings produced.

DEVELOPMENT OF STEEL MAKING CAPACITY

1. The electric steel melting plant at the Norfolk Navy Yard, as it is now constituted, has the largest electric steel melting capacity of any Navy Yard, and perhaps the largest melting capacity regardless of the process.

Side Blow Converter First Used

2. The first steel melting unit was a 2-ton, side-blow, Tropenas converter and was installed in the old foundry in 1913.

Add Basic Electric

3. In 1918, when the new foundry was built a 6-ton, bottom-conducting, basic Greaves-Etchells furnace was installed. This furnace has a 1500 k.v.a. substation. Regardless of what may be

† Published by permission of the Navy Department.

* Master Molder and Supervising Melter, respectively, Norfolk Navy Yard.

NOTE: This paper was presented at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

the disadvantages of this furnace, it has made many tons of good steel over the years and it had some advantages which were incorporated in the specifications of furnaces later installed. Due to its shape, it can be well overloaded and a number of 43,000 lb. alloy heats have been made in it, with heats of from 25,000 to 35,000 lb. being quite common.

Post-War Depression Period

4. When the post-war depression of 1921 came about, there was not sufficient work to keep this size electric furnace in commission, so the converter was again operated. About 1923, however, a 3-ton Greaves-Etchells furnace was installed. This had been formerly used at another Yard. With these two electric furnaces available, six castings, each requiring 63,000 lb. of alloy steel, were made in addition to regular routine work.

Install 1000 lb. Furnace for Special Work

5. In 1928, a 1000 lb. Lectromelt furnace was added with 375 k.v.a. substation, primarily for making small quantities of special steel and for test work. Subsequently this furnace has proved extremely valuable in pouring very thin wall castings of which many are required, and without it, it is doubtful that they could have been made successfully.

6. During 1933, the 3-ton Greaves-Etchells furnace was replaced with a modern 3-ton, top charge, Lectromelt furnace with a 3,000 k.v.a. substation. A tap changer is built on the transformer which gives a selection of any of four voltages by push-button control. The normal charge for this furnace is 16,000 to 18,000 lb. and heats as large as 24,000 lb. have been made.

Additional Furnaces Added

7. Since the first of the year the installation of two additional furnaces has been completed, a 500 lb. Lectromelt and a 12-ft. diameter top charge Swindell. The 500 lb. Lectromelt was supplied with an 800 k.v.a. substation. The 500 lb. furnace was installed, however, for use with the old 375 k.v.a. substation, previously used for the 1,000 lb. furnace. The 1000 lb. furnace was re-installed in connection with the new 800 k.v.a. substation, thereby giving both furnaces higher rating substations than are normally used.

Top Charge Furnace

8. The 12-ft. diameter, Swindell, top-charge furnace is supplied from a 6,000 k.v.a. substation with push button controlled tap changer.

9. One of the features of design insisted upon, as a result of the use of the old Greaves-Etchells furnace, was that the doors and tap hole should be ported or "dog-housed" out from the shell of the furnace. This allows the use of a flat door with the face of the door about 8-in. from the shell of the furnace. It is believed this cuts down drafts around the door and makes a tighter furnace.

10. Another feature of the specifications was that "tees" in place of "ells" were to be used on all water piping for ease of

Table 1
CLASS "B" STEEL¹

Period		No. of Tests	Elong., per cent	Reduction of Area, per cent	Yield Point, lb. per sq. in.	Ultimate Stress, lb. per sq. in.	Bend, Degrees
July 1941	Av.	125	30.1	48.9	43,264	69,008	180
	Low		26.0	38.5	37,500	62,000	
	High		35.0	58.5	51,500	76,750	
Sept. 15 to Oct. 15 1941	Av.	129	29.8	50.7	44,382	71,095	180
	Low		26.0	40.5	37,000	61,750	
	High		28.0	48.0	48,500	78,250	
Dec. 1941	Av.	161	29.77	49.76	44,943	71,403	180
	Low		24.5	37.5	39,000	65,000	
	High		35.0	58.0	53,000	82,250	
General Average Specifications			29.89-24.0	49.78-35.0	44,147 ²	70,502-60,000	180-120

clean out. The same specifications applied to the 3-ton Lectromelt when purchased. While it has not been necessary, up to the present, to push this furnace to its ultimate capacity, it is expected that under favorable conditions, heats weighing as much as 60,000 lb. can be melted.

FURNACES USED FOR MONEL AND SPECIAL ALLOYS

11. All of the steel is melted in electric furnaces on basic bottoms under two slags. The lime used is rice size and comes packed, 200 lb. in a steel drum. If it is slaked, it is not used. While the primary purpose of the paper is to discuss the manufacture of steel for castings, it may be well to digress for a moment to other

¹ 0.20 to 0.30 carbon, 0.60 per cent max. manganese, 0.40 per cent max. nickel,—1650°F. Anneal.

² 45 per cent of ultimate stress, not less than 30,000 lb.

uses of the furnaces. For the past several years, the Norfolk Navy Yard has manufactured synthetically in the electric furnace practically all of the monel ingots used by the Navy for making castings. In addition to this, the Yard has cast three heats of 20,000 lb. each of special silicon-monel for experimental propellers, as well as a number of smaller heats. From time to time, the small furnaces are used to make bronze hardeners out of non-ferrous scrap, resulting in considerable saving.

TYPES OF STEEL MADE AND RANGE OF CASTING SIZES

12. A number of different types of steel are made including plain, hard, nickel-chromium, carbon-molybdenum, ordnance, austenitic manganese, and corrosion resistant. These steels are poured into various size castings with sections ranging from $\frac{1}{8}$ -in. to 18-in.; from simple anchor castings, to very complicated turbine castings; from castings weighing a few ounces, to those requiring 63,000 lb. to pour. It can, therefore, be seen that many different types of castings are produced.

FURNACES OPERATED ON INTERMITTENT BASIS

13. In a steel foundry such as that at the Norfolk Navy Yard, operation of the furnaces normally is on an intermittent basis.

Refractories

14. Refractory material which may be satisfactory in continuous operation, would not necessarily be satisfactory under our normal conditions.

15. The Greaves-Etchells furnace, which requires a conducting hearth, was necessarily a single rammed bottom, that is, the whole bottom of 13-in. magnesite was rammed before any burning-in. This gave a soft bottom which readily slaked between heats and is one of the drawbacks of this type of furnace.

16. The first two Lectromelts installed had burned-in magnesite bottoms. The best bottom material found up to the present, however, has been some specially prepared magnesite, a fine grade and a coarse grade both with bonding material already added. This is mixed with water containing a small percentage of silicate of soda and in the proportion of two parts of fine to one of coarse and rammed in cold.

Table 2
CLASS "CMO" STEEL³

<i>Period</i>		<i>No. of Tests</i>	<i>Elong., per cent</i>	<i>Reduction of Area, per cent</i>	<i>Yield Point, lb. per sq. in.</i>	<i>Ultimate Stress, lb. per sq. in.</i>	<i>Bend, Degrees</i>
July 1941	Av. Low High	6	27.6 26.0 28.5	45.1 43.0 48.5	48,725 44,000 52,350	73,541 71,000 78,500	180
Aug. 1941	Av. Low High	2	28.5 28.0 29.0	49.25 49.0 49.5	51,625 50,750 52,500	76,500 76,500 76,500	180
Sept. 1941	Av. Low High	5	26.2 23.5 29.0	44.4 39.0 52.0	52,400 50,000 53,500	79,100 77,750 80,750	180
Oct. 1941	Av. Low High	14	28.32 26.0 32.5	50.01 40.9 55.0	48,893 44,250 52,000	73,714 67,250 77,250	180
Nov. 1941	Av. Low High	7	27.2 25.0 29.0	45.8 41.0 51.0	50,786 47,000 53,500	76,107 69,000 80,750	180
Dec. 1941	Av. Low High	12	25.8- 26.0 32.0	48.5 44.5 53.0	48,250 44,450 53,000	73,500 69,000 78,950	180
General Average			27.27	46.73	50,113	75,410	180
Specifications			20.0	30.0	35,000	65,000	120

17. Minor repairs between continuous heats are made with dolomite, but when the furnace gets cold, the bottom is repaired with the same material and in the same manner as the original bottom. In the 1000 lb. furnace, this special magnesite has been found to be the only material which would stand up well under the very high temperatures at which the metal has to be melted to run the thinnest castings. Because of intermittent operation, a good grade of fire clay brick will give better results than silica brick, which spall greatly under such operation. Fire brick roofs have been used for several years.

Comparison of 1000 lb. and 3-Ton Furnace Operation

18. The 1000 lb. furnace is operated for about 20 heats, the roof lifted off and the bottom and banks patched by adding about 2-in. of bottom material. After patching, six heats of about 1500 lb. are made prior to the regular 2000-lb. heats. The fire brick roof is good for 40 to 50 heats. On the 3-ton furnace with a fire brick side wall lining and with a fire brick roof, 40 to 50 heats can be made between general repairs, at which time the roof is renewed and the bottom is patched by adding about 1-in. of material on the

³ 0.20 to 0.30 per cent carbon, 0.50 to 0.70 per cent manganese, 0.50 per cent molybdenum,—1750°F. and 1650°F. double anneal.

flat and 3 to 4 in. on the banks. If a special high alloy or monel heat is to be made, the top crust is removed and replaced with new material. If furnace life seems a little on the low side, it must be borne in mind that they are operating with charges above rated capacity.

UNORTHODOX METHODS?

19. The term "unorthodox" has been applied descriptively

Table 3
CLASS "F" STEEL⁴

<i>Period</i>		<i>No. of Tests</i>	<i>Elong., per cent</i>	<i>Reduction of Area, per cent</i>	<i>Yield Point, lb. per sq. in.</i>	<i>Ultimate Stress, lb. per sq. in.</i>	<i>Bend, Degrees</i>
July 1941	Av.	17	23.18	42.38	66,063	102,855	180
	Low		19.5	30.0	61,500	93,500	
	High		27.0	49.0	71,000	114,285	
Aug. 1941	Av.	69	23.74	47.01	63,814	95,012	180
	Low		22.5	39.0	50,000	71,500	
	High		32.0	55.0	74,000	105,000	
Sept. 1941	Av.	80	25.02	46.48	62,284	93,945	180
	Low		17.0	28.5	43,350	71,000	
	High		30.0	60.0	74,500	109,750	
Oct. 1941	Av.	64	25.2	46.7	63,591	92,794	180
	Low		19.5	37.5	56,500	85,500	
	High		29.0	54.5	73,250	104,750	
Nov. 1941	Av.	33	25.85	47.23	60,535	91,245	180
	Low		22.0	40.0	55,750	82,750	
	High		28.0	54.5	71,500	101,250	
Dec. 1941	Av.	10	26.55	50.6	61,900	92,475	180
	Low		23.0	44.0	55,000	79,750	
	High		31.0	56.0	66,250	100,500	
General Average			24.92	46.73	63,030	94,704	180
Specifications			22.0	35.0	53,000	85,000	120

several times to some methods used at the Norfolk Navy Yard in the manufacture of steel castings. All steel is made, however, in accordance with Navy specifications, both chemical and physical, and many castings have been subjected to radiographic inspection since 1930. We think, therefore, in terms of results and not of methods. Any method which will better enable us to meet these conditions is "orthodox" as far as we are concerned.

MAKING A 15,000 LB. HEAT

20. The following is the history of a 15,000 lb. heat. Three hundred lb. of limestone and 200 lb. of lime will give about the right

⁴ 0.35 per cent carbon, 1.50 per cent nickel, 1.15 per cent manganese,—1650°F. double anneal.

amount of slag at the proper fluidity which is believed to affect the ductility of the steel. Required nickel is included in the charge.

21. Wash metal is used according to the condition of scrap. Melting down is done with 235 volts with usually a rather fluid dead slag. The voltage is then changed to 110 and, if a good action in the bath does not occur in about 10 min., a shovelful or two of iron ore is added. This ore is allowed to work until the slag has a good action and thickens up which usually requires about 15 min.

Taking off First Slag

22. At this stage of the operation, 0.15 per cent silicon is added just before slagging off. This kills the heat and permits a good clean-off of the slag.

23. Phosphorus in the charge is on the low side which permits this silicon addition before pulling the first slag. After the slag-off, 15 more points of silicon and all of the manganese and alloys the bath will take without freezing are added. If much recarburizing is required coal is added after pulling the first slag.

Second Slag

24. The second slag consists of 300 lb. of lime, 100 lb. of fluorspar and 90 lb. of cement; about 10 lb. of coke dust, if neces-

Table 4
SPECIAL STEELS AND ALLOYS

	<i>Elong., per cent</i>	<i>Reduction of Area, per cent</i>	<i>Yield Point, lb. per sq. in.</i>	<i>Ultimate Stress, lb. per sq. in.</i>	<i>Bend, Degrees</i>	<i>Brinell</i>
<i>Ordnance</i> ⁵						
Specifications	18.0	45.0	70,000	95,000	120	
Results	23.0	41.0	70,600	100,700	180	
<i>Chain</i> ⁶						
Specifications	12.0	20.0	93,700	125,000	None	
Results	18.0	43.0	116,500	134,250	None made	
<i>Special Track</i> ⁷						
Specifications	24.0	45.0	70,000	100,000	180	190-210
Results	26.0	48.0	75,600	104,500	180	200
<i>Corrosion Resistant</i>						
Specifications	35.0	40.0	40% Tensile	70,000	None	
Results	56.0	59.8	35,540	71,540	180	
<i>Silicon Monel</i>						
Specifications	10.0	-	70,000	100,000	None	
Results	21.0	-	73,950	108,080	None made	

⁵ 1650°F., Air Cool, 1350°F. draw.

⁶ 0.60 per cent chromium, 1.50 per cent nickel, 0.25 per cent molybdenum,—1525°F. water quench, 1100°F. draw.

⁷ To be straight annealed only.

sary, to build up the carbon. After this slag has been in the furnace from 3 to 5 min., it is sprinkled with 3 or 4 shovelful of lime mixed with aluminum borings or turnings in the proportion of 3 parts of lime to one part of aluminum by volume. Formerly aluminum shot in proportion of one part to 9 parts of lime was used, but for some time aluminum turnings and borings from the machine shop have been substituted. In from 5 to 10 min., just as soon as the slag starts to melt, a foamy white slag forms. Usually nothing more is added except lime. About 300 lb. is added, if the slag thins down enough, as on the second slag an attempt is made to finish with a ratio of 40 lb. of lime to every 1000 lb. of metal.

25. Sometimes a little more mixed lime and aluminum is added and, if the slag gets too thin, a little coke dust is added. Tests are taken for preliminary analyses, and after reported on, all the remaining alloys are added. About 5 min. before tapping, another 5 to 10 points of silicon and 3 lb. of 40 per cent ferro-titanium per ton of metal are introduced. A small shovelful of the lime and aluminum mixture is added on top of the ferro-titanium to drive it into the metal.

26. If the silicon content of the steel is to finish under 0.20 per cent, 0.05 per cent aluminum is added in the furnace just before tapping. One lb. of 30-35 per cent calcium-silicide per ton of metal is added in the ladle when tapping. The steel is now ready for pouring.

CONTROL OF HEAT OBTAINED

27. It is felt that the foregoing practice gives perfect control of the heat at all times. The refining slag, being always white, gives control of carbon within one point and other alloys may be kept within close limits.

28. It is recognized that the melting practices described differ somewhat from general practice; however, they have worked out well for this particular foundry. Sound castings are produced consistently and there has been little trouble meeting property requirements.

29. The Naval Research Laboratory investigators have informed the authors that fluidity tests poured with this steel have produced longer spirals than with steel made in their acid induction furnaces and poured at the same temperatures as determined by optical pyrometers.

DATA PRESENTED ON STEEL TESTS

30. Tables 1, 2 and 3 give results of actual routine tests of steels of Class B, Class CMO and Class F.

31. In addition to the more or less regular steels of Tables 1, 2 and 3, Table 4 gives the specifications and representative results of special steels and alloys the Yard has been called upon to make.

DISCUSSION

Presiding: JOHN HOWE HALL, Philadelphia, Pa.

Co-Chairman: C. E. SIMS, Battelle Memorial Institute, Columbus, Ohio.

CHAIRMAN HALL: One thing that strikes me in this paper is that the authors describe practice, using what might be called complete reduction, with white slag or carbide slag, and make quite a point of the fact that they have good fluidity in their steel. It is not so many years since we heard it was hard to get fluidity in connection with completely reduced electric basic steel.

F. A. MELMOTH¹: I think so much discussion has taken place on this particular point, little is left to say. The consensus is that with strongly reducing conditions basic electric steel is more difficult to pour in light sections than less strongly reduced acid steel. It is true that the same opinion is largely held by furnace operators of acid steel which has not been subjected to sufficiently oxidizing conditions during processing.

A reference is made in the paper to unorthodoxy of the methods used. It would appear that the major unorthodoxy is the use of aluminum in the making of the finishing slag. I presume that this is used on account of its strongly reducing effect on any slag oxides, and I would ask the authors if, in view of the present shortage of aluminum and the difficulty experienced by other steel founders in getting even the small relatively insignificant quantities for final deoxidation, there are not other equally effective methods of producing the desired effect.

H. BLOSJO²: You say you control your carbon within a point. Why is it, then, the physical properties on the Class B steel vary from 60,000 to 100,000 lbs. per sq. in.?

MR. BRINSON: I do not know just how closely we control the other elements, but we do control the carbon. Sometimes we have to make a heat to cover a large variety and there may be some temperature differences there that may affect it, but our chemical records actually show that our carbon is kept pretty close.

¹ Detroit Steel Castings Co., Detroit, Mich.

² Minneapolis Electric Steel Castings Co., Minneapolis, Minn.

CHAIRMAN HALL: There are not so many basic electric operators. The operators of converters are a little inclined to chuckle over what we have just heard from Mr. Melmoth about over-oxidation and how we are able to make thoroughly reduced basic steels by continuing the oxidized conditions almost up to the finish of the heat.

MEMBER: You say you took the electric capacity from the manufacturer and then increased it to be sure you had enough power. By how much did you increase it?

MR. BRINSON: When we bought a 1000 lb. furnace we got a power plant of 375 k.v.a. When we got the 3-ton furnace, I think the manufacturer said that 2500 k.v.a. was sufficient and we bought a 3000 k.v.a. transformer. When we bought a 500 lb. furnace we bought an 800 k.v.a. transformer. We put this on the 1000 lb. furnace and switched the 375 k.v.a. transformer to the 500 lb. furnace. The manufacturer said a 5000 k.v.a. transformer was sufficient on the 12 ft. furnace, so we bought a 6000 k.v.a. transformer. We do not believe in running the power plant too close to maximum capacity when the furnace is overloaded.

MR. BLOSJO: In our plant we meet two or three different specifications with the same heat. How can you meet your chemical specifications on a Navy Class B and still get a 100,000 lb. per sq. in. tensile strength with a full anneal? There is a maximum of 30 points carbon and 60 manganese.

MR. BRINSON: With the variation in physical properties, I do not think it can be done except when properties are close together. What we tried to do is meet the minimum and keep well over it. We do not try to just barely beat the minimum.

MESSRS. BRINSON AND ANDERSON (*authors' closure*): We want to thank every one who took part in the discussion to bring out the various points, especially Mr. Blosjo who called to our attention the unusually high physical properties shown from one heat of Class B steel. It can be appreciated that in commercial practice the source of scrap and analysis is usually known. In our practice where a number of different analyses, plain and alloy, are called for in the plates and shapes, forgings, etc., used in ship building, it is extremely difficult to keep all the scrap separated, this being especially true in the case of old material removed from a ship after several years use, although an attempt is made to do it.

I recall some time ago, when the Navy Department placed a maximum on nickel content of castings which were to be subsequently welded on shipboard, that we especially selected a heat of scrap, every piece of which was thought to be at least 20 years old, yet the heat melted down 28 points nickel. On this basis we unknowingly sometimes have alloys in steel of which we are not aware. This turned out to be the case in the point mentioned by Mr. Blosjo and there has been substituted an actual heat which was in conformity to all chemical specifications of Class B steel.

The wide variations in results of Class B heats are further due to differences in annealing; a number of the heats being anchor heats which require a 72 hour anneal. It is also a matter of record with us that we have met the specifications for Classes B, D and A steel with the same heat by keeping the carbon just under the maximum (at that time 0.30) for Class B steel, but usually we try to suit the steel to the specifications.

The Problems of Making Large Castings

BY A. LEBESCH*, W. A. HAMBLEY* AND K. GEIST*,
MILWAUKEE, WIS.

Abstract

This paper discusses the problems involved in making large castings and the authors' procedures in solving them. They place the problems involved under two broad headings, namely, those to be solved before the job enters the foundry, and those involved in the actual making of the casting, covering, under the first heading, design, metal specifications, use of pit or flask, manner of parting the pattern and mold and placing, securing and venting cores, whether to use patterns, cores or sweeps, ease of cleaning the casting, gating and risering. Under the second heading, the authors discuss making a casting in a pit, outlining in detail the procedure of ramming the pit, drying the mold, coring the mold, placing the cope, placing the runner boxes, pouring the mold and cooling the casting.

1. There are so many problems to be solved in making a large casting that the authors felt it might be of some value to the industry as a whole if they were to set down for discussion and criticism the procedures used by them. These procedures are not to be construed as infallible, nor do we suggest that they are the only ones, but they have been used for some time with excellent results. In many localities, these same procedures may not be the most economical ones, but, when a casting involving many tons is to be made, we feel that the most economical way to produce it is by methods offering the greatest possibilities of success, since a defective casting most certainly increases the costs.

2. The methods of laying out and making large castings are more or less the same whether there is only one to make or several. Even when it might be classed as a production job, as the order calls for one or more a week, these same procedures would be followed before the first one would be delivered. The problems involved may be placed under two broad headings. First, those to

* Superintendent No. 1 Foundry, Foundry Metallurgist, and Student Metallurgical Engineer, respectively, Allis-Chalmers Mfg. Co.

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be solved before the job enters the foundry. Second, those involved in actually making the casting.

PROBLEMS TO BE SOLVED BEFORE THE JOB ENTERS THE FOUNDRY

3. After a large casting has been designed by the engineers, the first two questions of importance are: How can it be made? and What is the best method? It is very important that conferences be called wherein the foundry and pattern shop management, the metallurgist and the engineer discuss and iron out as many difficulties as possible before the design is approved. These conferences may take several weeks before approval is given and the blueprints are sent to the pattern shops to start the work on the patterns and core boxes. Some of the problems which arise that require studying and which must be solved are discussed in the following paragraphs.

Problems of Design

4. Is the design metallurgically correct? Most of the problems in design arise from the engineer failing to take into account the contraction or shrinkage characteristics of the metal. Isolated heavy sections must be properly taken care of by gating and risering or they must be eliminated. All sections of the casting should be as nearly uniform in thickness as possible and, when a change in section thickness is necessary, it must be done gradually, otherwise defects such as shrinks, hot tears, checks and cracks are bound to occur, as well as the possibility of excessive stressing causing failures later. Corners at adjoining sections must have ample fillets to prevent checks and cracks, but care must be taken to avoid being too generous. Too generous fillets tend to create hot spots which also are liable to occur at "T" and "X" sections. To minimize the possibilities of defects due to design, these problems must be considered and solved.

Metal Specifications

5. What grade of metal is required? Interwoven with the problems of design is the question of metal specifications. Most engineers, knowing the service demanded from the casting, specify the grade of metal necessary, either by physical or chemical specifications, or by both. Learning the controlling metal sections and the service demanded, the foundry metallurgist, with the knowledge of the characteristics of his available mixtures, can be of great serv-

ice to the engineers in working out an economical metal. Only in rare cases are both the chemical and physical specifications necessary and should be avoided. Many times alloy additions are specified which are unnecessary and a positive waste of material. On the other hand, it is sometimes necessary to ask for an alloy addition to meet the service demanded. Knowing the metal specifications, the temperatures of pouring can be decided, as well as many other problems, such as the best sand, facing and washes. The metal specifications also will have a bearing on the gating and risering, the slacking-out or removal of cores, as well as problems of accelerating or retarding the cooling rate.

Use of Pit or Flask

6. Should the job be made in a pit or flask? This choice usually depends upon the design and sometimes on the number of castings required. If a number of castings are to be made and the design is suitable, it may be more economical to use a flask, even though the flask must be made. These flasks can be made in open sand, many times using over-iron. When the job is completed, they can be scrapped and credit received for the material as cast iron scrap. Though the job must stand the expense of making the flask, it has many advantages over a pit, which makes the flask desirable to use, if possible. Such factors as ease in venting, in tying in cores, as well as securing the cores, in drawing split pieces, in taking the mold apart to remove patterns, in slacking-out or removing cores, are all factors in favor of using a flask, and make the job easier and production faster. In making this decision one must consider crane facilities, too. The weight of rammed sand and flask sometimes runs into many tons, and may be beyond the capacity of the cranes. The height of the casting and the headroom available have a bearing on the decision.

7. We have neglected to mention the possibilities of making the casting in loam, as the majority of foundries have no facilities for loam work. The big advantage of making an intricate casting in loam is that the pattern expense is low but this is offset to a large extent by the extra time necessary to make the mold.

Parting the Pattern and Mold

8. How is the pattern and mold to be parted? This question is often a difficult one, especially on an intricate design. If other castings of the same general design have been made before, this

problem probably can be solved by consulting the layout board. If the design is entirely new and complicated, a model is made and studied. It is surprising how clear a difficult problem can become when a model is available. Problems such as setting the cores, sections going into the cope if in a pit, the number and height of cheeks if using a flask, can be solved readily through study of a model.

Placing, Securing and Venting Cores

9. How to place, secure and vent the cores? These problems must be solved before the job leaves the pattern shop. Here, also, a model is of great help. In a large casting, many tons of cores are used and these must be secured and vented. In going over the design, it may be found that the engineer wants a cavity and yet has allowed no way to secure the core. It may be necessary to request a hole in the casting, which later must be plugged, so that sufficient core print can be secured. This problem must be settled with the engineer who knows where he can or cannot have a hole. If sufficient print cannot be obtained, it is necessary to see how the core might be bolted to another core, secured in the bed of the pit or tied to the cope. This may indeed be a serious problem. Then, in venting the cores, sufficient prints must be allowed, and it may even be necessary to add another one to properly take off the gas. In pit molding, pipes can be placed in the coke beds at the proper places, but in a flask, the pipes will have to be secured sufficiently to prevent the pressure from forcing iron into the vents or causing a runoff.

Patterns, Core Boxes and Sweeps

10. It must be decided whether it is more economical to make the job using all cores and, consequently, core boxes, or to build a pattern. This is dependent somewhat upon the design and number of castings to be made. It also may be possible to use sweeps for some cores or parts and effect a saving. If loose pieces are used, it must be decided where they are necessary and where they must be tied to draw the pattern, keeping in mind the fact that the whole mold must be pulled apart after ramming to remove the patterns. Quite often these pieces must be tied or fastened to the cope and drawn with it.

Cleaning Castings

11. The removal of rods, sand and arbors may present many

difficulties of which the engineer never thought. Small, rounded cavities, surrounded by heavy sections, as well as isolated cavities, present cleaning room difficulties for which special equipment may be needed.

Gating and Riser

12. How to gate and riser the casting? We mention this subject briefly because to cover it adequately would necessitate writing several books. The main thought is placing the gates and risers to properly pour and feed the casting. The gates must be attached to sections having proper thickness to allow free and smooth flow of the metal. Risers must be placed to properly feed the casting and yet not affect the use. Gates or risers in pressure-tight sections, where the specifications call for water- or oil-tight metal, must be avoided if possible, to eliminate possibilities of porosity and leakers. Many large castings require only one ladle of iron and a simple system of gating and risering, but large castings of intricate design generally require two or three and even more, with a complex system of gates and risers.

13. These and many more questions are solved before the design is approved. All the problems are not engineering and many, such as ample draft and parting lines, must be worked out between the foundry and pattern shop. The making of any large casting, successfully and economically, is not the work of one man but the work of the whole organization functioning in harmony.

MAKING THE CASTING IN THE FOUNDRY

Making a Casting in a Pit

14. To outline a procedure for a definite type of equipment, let us consider making a casting in a pit. All of our pits are stationary or permanent, being made with concrete walls and bottom. They vary from 10 to 15 ft. in width, from 24 to 40 ft. in length, and are 14 ft. deep. The length of the pit can be shortened, if desired, by means of heavy plates that are wedged and braced in place. These plates are made in sections, the width of the pit, and about 5 ft. high, so as to facilitate handling. Along the four side-walls, heavy eye-bolts are imbedded in the concrete every 3 ft., which enables the cope to be tied down and secured. The cope of all pits generally is made with a flask, the width of the pit and the desired length. Figure 1 shows the general view of a pit.

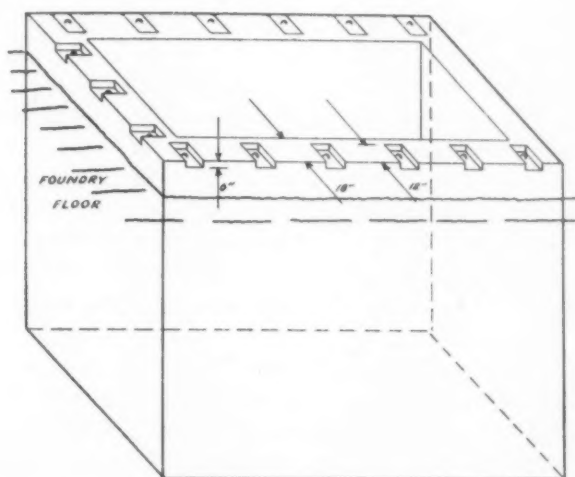


FIG. 1—GENERAL VIEW OF A CASTING PIT.

Ramming the Pit

15. To start ramming a pit, the overall dimensions of the pattern are obtained from the pattern checker and the pit is rammed with heap sand to about 16-in. from where the bottom of the pattern is located. An 8-in. bed of chestnut-size coke is laid down on top of this sand. Vent pipes that are to lead the gases off from the bottom or bed are placed on the coke bed and along the sides. These pipes are 4-in. in diameter and run to the top of the pit where they are carried up through the cope by additional pipe, rammed in the cope. One of these pipes is placed every 6 ft. along the side-walls so that for a 24-ft. pit there would be three vent pipes on each side, plus a pipe for each of the four corners. The coke bed is then covered with burlap, to prevent the sand from being rammed into the coke. Since burlap is now a scarce article, straw or heavy paper is used instead. A 6-in. layer of sand is now rammed on top of the coke bed and levelled off to the bottom of the pattern.

16. The pattern or bottom section of the pattern, depending on the design, is then located in the pit. It is firmly braced by one or more sections to prevent any movement during the ramming, as shown in Fig. 2. Heavy weights also are used. Weights may be used alone or in conjunction with braces, depending again on the design and size of the patterns. Regardless of how it is weighted

and braced, the pattern must remain solid and stationary during the ramming.

17. After the pattern is located, braced and weighted, ramming is begun. The mold is rammed by progressive steps of about 6 to 8-in. to a ram. The procedure is to lay up a layer of facing 6 to 8-in. deep and about 4-in. thick against the face of the pattern. This facing is peened or rammed and is then backed up by heap sand which is rammed in by a traction sandslinger or air rammers. Care is taken to see that edges next to the pattern and the sides of the pit are solid. These steps are continued until the whole mold is completed.

18. The heap sand used averages 70 permeability, 8.5 lb. per sq. in. green compression strength and 7.0 per cent moisture. This sand is very coarse and is rammed very hard. It is composed of knockout sand, which is mostly lake sand, and has a grain fineness of 20, containing no clay. The facing sand is made up as follows: 62 gal. of lake sand; 44 gal. of molding sand, which has a grain size of 65 average and a clay content of 30 per cent; 32 gal. of old or heap sand and 4 gal. of core compound. This facing is mixed in a muller-type mixer and averages 100 permeability, 8.5 lb. per sq. in. green compression strength and 6.5 per cent moisture. The dry strength is over 280 lb. per sq. in. which is the limit of the testing machine on compression. This facing sand also is used to make all the cores or facing for the cores.

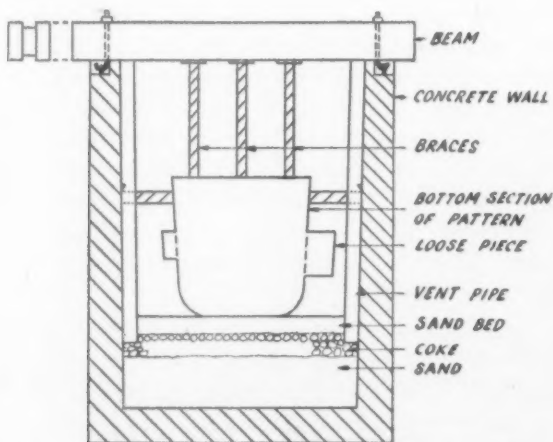


FIG. 2—VIEW OF CASTING PIT SHOWING BRACING OF PATTERN TO PREVENT MOVEMENT DURING RAMMING.

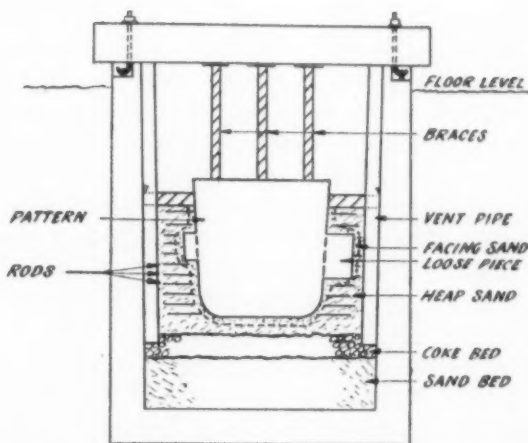


FIG. 3—VIEW OF CASTING PIT SHOWING RODS PLACED DURING RAMMING TO HOLD THE SAND AND PREVENT ITS TEARING WHEN PATTERN IS DRAWN.

19. As the ramming goes on, all rods, hooks, anchors and core bearings are imbedded in their proper places. After each ram or step, rods are placed so that the ends will be within one-in. of the pattern face to hold the sand and keep it from tearing when the pattern is drawn as shown in Fig. 3. Naturally, the principal function of the rods is reinforcement. Bearings necessary for cores, so that their weight will not crush the face of the mold, are bedded and rammed in place. These bearings are usually pieces of rail or $\frac{1}{4}$ -in. plate. Quite often allowances must be made for pads to insure fusing of heavy studs and chaplets. These pads appear as heavy sections of metal after casting and usually must be chipped off, but in some cases they are necessary to provide a factor of safety against leaks. Bearings necessary for the bottom must be rammed and bedded in place before setting the pattern.

20. Having determined the number and size of gates, as well as the location of them, they are placed during the ramming. Care must be taken to properly box off the vent-plugs back of the prints for the cores to insure positive escape of the gases. These must be rammed up later when setting the cores. These matters are incidental to the ramming as is roughing up or wetting each layer before the next one is rammed to insure a good joint between them, but they must be watched.

Drying the Mold

21. As soon as the pit has been properly rammed and the joint finished, the cope flask is set in place. Next the number of heaters or stoves required to dry the mold must be determined. This is done by spacing pipes 5 ft. apart and from 18 to 20-in. from the side walls. Four to six pipes are connected to one heater. These pipes, 4-in. in diameter, are wedged and firmly secured to the cope bars. Gates, risers, and vent pipes are placed, care being taken to see that they are properly located. A layer of facing is riddled on the pattern, gagers are set, and the cope is rammed in layers similar to ramming the pit.

22. After the cope is rammed, slides and guides are placed for drawing it. It is drawn off and removed to a spot for finishing. The pattern is then rapped, hooked to a crane and drawn. Usually there are a few corners and pockets which break out and must be patched. All corners and crevices are nailed, even though they have been well rodded while ramming. Bed plates for stud and chaplet bearings are set. These are usually small steel plates



FIG. 4—HEATERS PLACED FOR DRYING THE MOLD.

about $4 \times 4 \times \frac{1}{4}$ -in. and are used to prevent the cores from damaging or crushing the face of the mold. After all patching and nailing has been done, the mold is sprayed with a good grade of plumbago to which a binder has been added. This is slicked and washed again and the mold is ready for the heaters. Figure 4 shows the heaters placed for drying.

23. Where the heater pipes enter the mold, tins are set on bricks to keep the direct heat from the face of the mold and prevent burning it. A burned mold-face is just as detrimental to a sound casting as a wet or underdried one. Rails are placed on the top edge of the pit, and the cope, which has been finished, is placed on the rails, thus leaving a space between the cope and drag to allow the heat to circulate and dry the joints. Crevices and holes around these joints are sealed with mud and loam, leaving the corners open to allow the steam to escape. The vents from the coke bed are left open while all the other vents, gates and risers on the cope are covered. The main thought is to keep the heat in the mold and make it circulate.

24. The mold is now ready for the heater pipes which are 3-in. in diameter and are set in through the 4-in. pipes that were rammed in the cope. These pipes are lowered to within 12-in. of the tins that were previously placed in the mold, and connected to the stoves. The stoves are regular mold stoves burning crude oil but could be used with coke or charcoal. From tests, however, we have found crude oil to be the cheapest. It has the following further advantages: (1) makes it unnecessary to tend the fire, (2) provides more uniform heat, (3) does away with necessity of hauling coke to stove and ashes away.

25. The fires are started and a slow fire is continued for 12 hours or more to allow the steam to escape slowly. The heat is then increased and the drying operations continued until the mold is thoroughly dry. This generally takes from 90 to 120 hours, depending on the size. The mold must be dried at least 4-in. back from the surface and possibly completely dried, depending entirely on the time necessary to set the cores and pour off. As setting the cores may take up to 3 weeks, a shallow dry of 4-in. would not be sufficient and would cause scabs and blows. From thermocouples placed at various spots in a large mold, it has been found that the mold surface has risen to 600°F. in 48 hours while 5-in. back, it was 425°F. After 5 days the mold surface was 725 to 750°F., 5-in. back it was 600°F. and the whole mold was completely dried.

Coring the Mold

26. After the mold has been completely dried, the stoves are disconnected, the 3-in. heater pipes removed and the cope lifted off preparatory to coring. If there is some question as to the thorough dryness of the mold, sand is dug out in some core print and the depth of penetration measured. However, by the use of thermocouples, the depth of penetration now is known. While the mold is luke-warm, it is covered with a light wash of the plumbago mix and coring is started.

27. The centers of large cores are filled with coke and are faced with about 10-in. of facing sand. All hooks, rods, and arbors are placed during the ramming and care is taken to insure that they are secure. Hooks must be placed so as to properly balance the core while it is being handled by the crane and must be secure enough to furnish a large factor of safety. Many cores weigh several tons or more and are handled by cranes. No chances of having one fall apart or break up while handling can be taken.

28. As in the mold, all corners and ribs of cores are secured and nailed, after the core boxes are drawn. They are then slicked and finished as completely as possible and baked. Depending on their size, the baking time varies from 8 to 48 hours at temperatures between 500 and 650°F. After the core has been baked, and while it is luke-warm, it is finished and washed with the same plumbago mix that is used on the mold. Here the correct temperature is important. If the core is washed while too hot, the blacking tends to form steam holes which may cause a rough casting. In addition, the core tends to contract on further cooling, and, as it contracts, the heavy coating of blacking buckles, tends to peel off and blisters. If the wash is applied when the core is too cold, the moisture is not evaporated and trouble will develop from scabs and blows. All cores that are blackwashed while cold must be put back in the oven and dried.

29. The finished cores are now ready for the mold. They may have to be stored for several days, or even weeks, before they are used, but a black sand core keeps its strength and will seldom have to be put back in the ovens, unless stored where it may have become wet. As each core is being set, vent pipes are properly located in the boxed-off areas and rammed to prevent iron from entering them. The cores are set in the mold using gauges and straight-edges, making sure that the proper metal thicknesses are maintained by chaplets and studs. The hooks are covered by facing which is rammed

in and dried by small charcoal fires. These spots are then finished in the regular way with plumbago wash. Care must be taken to see that these spots are thoroughly dry to prevent scabs.

Placing the Cope

30. The mold is ready for the cope as soon as the cores are set and the hook holes finished and dried. Flour is placed on the core prints and joints, clay balls are placed on the mold surfaces to gauge the metal thickness and the cope is tried on. The cope is removed and the mold is thoroughly inspected to see that no crushes have taken place, that the vents, gates and risers line up and everything touches that should. If everything is satisfactory, dough or clay rolls are placed along the joints, chaplets and studs set, and the cope placed on.

31. Usually all risers are built up on the cope before it is finally lowered into place. This insures that the mold is free from dirt falling in during ramming of the risers. After the cope has been fitted into place, plates are wedged between the flask and the concrete walls of the pit to prevent the cope from being drawn down too far and causing a crush. One or more rails are placed at right angles to the flask bars, depending on the length and width of the flask. These rails are placed along the top of the cope and beams are then placed parallel to the flask bars on top of the rails. These beams are from 12 to 18-in. high, 8 to 10-in. wide and 10 ft. or more in length, and they are placed about 3 ft. apart. As the sides of the cope flask are from 6 to 8-in. above the bars, this leaves space between the beams, rails and bars for effective wedging.

32. The beams are bolted to the permanent eye-bolts in the sides of the pit and the rails wedged under the beams where they cross. The bars of the flask are then wedged under the rails where they cross so that there is a crisscross pattern of beams and rails, and all bars are firmly secured. This may seem like unnecessary work but when the enormous pressure built up in a large mold during the pouring is considered, too many precautions cannot be taken to insure a good casting. The authors have seen heavy eye-bolts straightened out, due to pressure on the cope.

Placing the Runner Boxes

33. After the tying down has been completed, the runner boxes are placed on and secured. The runner boxes are built separately

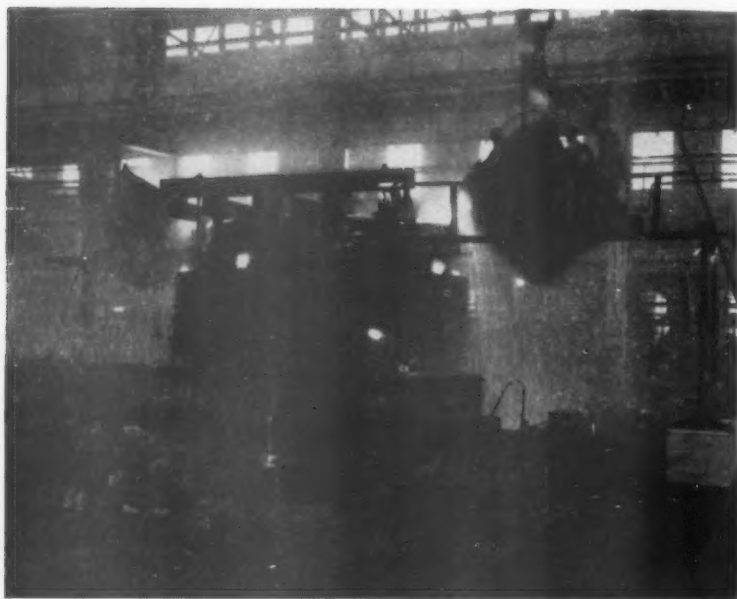


FIG. 5—POURING A LARGE MOLD.

and are made from a number of standard forms which have been cast in open sand. They are from 3 to 9 ft. long, 24 to 30-in. wide and 16-in. deep. The boxes are made up by using brick and loam, and are dried and blackwashed. The choice of the runner box depends somewhat on the crane facilities as, using three cranes, 28 ft. must be allowed between the outside ladles of metal.

Pouring the Mold

34. The iron is poured into the mold at temperatures ranging from 2400 to 2600°F., depending on the type of metal and the section thickness. Fig. 5 shows the pouring of a large mold. Gates are immediately frozen by dousing with water and the feeding of the risers started. Since all large castings are fed through risers by churning with $\frac{1}{2}$ -in. rods, feed iron must be ready at all times to keep the risers touched up. The question of feeding large castings by various methods always has been a highly debatable one, and, as books have been written on gating and risering, the authors mention that they believe the above is the cheapest way to feed large castings.

Cooling the Casting

35. After a large casting has been poured, it is allowed to lie in the pit and cool for a few days before the cope is stripped off. This is dependent on the design, as it is often necessary to strip the cope to remove some cores or slack them out. In these cases, the casting is covered up with sand and allowed to cool slowly. Most big castings are allowed to remain in the sand from a week to 10 days or more. This allows them to stress relieve themselves somewhat. All precautions possible should be taken to insure proper cooling to avoid cracks and highly stressed castings. Figure 6 shows the cooling rate for a 42-ton, crusher main-frame. Thermocouples were placed as noted and the cope and cheek removed when the temperatures were at 300°F. The casting was removed from the pit 4 days later, while still at 200°F. The casting was allowed to cool to room temperature in the cleaning room before cleaning operations were started.

ACKNOWLEDGMENT

36. With a few exceptions, the making of a large casting in a flask follows the same procedures as making one in a pit. Ob-

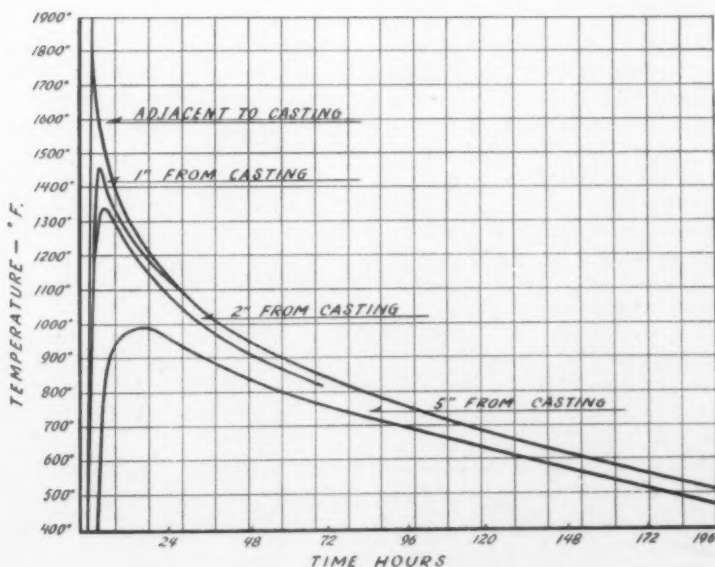


FIG. 6—COOLING RATE FOR 42-TON CRUSHER MAIN-FRAME.

viously, many small details have been omitted in presenting the problems of making large castings. However, the authors have attempted to give a picture of the most important problems encountered and their way of solving them.

37. The authors are indebted to J. A. Leisk, general superintendent of foundries and pattern shops, for his generous help in editing this paper.

DISCUSSION

Presiding: DR. H. RIES, Technical Director, A.F.A. Foundry Sand Research Committee, Ithaca, N. Y.

Co-Chairman: H. A. DEANE, Brake Shoe & Castings Div., American Brake Shoe & Foundry Co., New York, N. Y.

MEMBER: What is the thickness of the concrete wall?

MR. HAMBLEY: 18-in.

S. APPELBY¹: At what temperature do you dry the large, heavy molds in the pit?

MR. HAMBLEY: By using a thermocouple we have found that the face of the mold will be at 725°F. after 5 days.

MR. APPELBY: Do these oil type heaters deliver a temperature of 700°F.?

MR. HAMBLEY: Yes, at the end of 90 hours.

MR. APPELBY: Why does it take 90 hours?

MR. HAMBLEY: It takes 48 hours to get to 600°F. at the mold face, and the temperature has penetrated around 7½-in. Five-in. back of the face of the mold, the temperature is around 425°F. If it requires 3 weeks to set the cores, this may not be long enough, because the moisture farther back in the pit may come back out and ruin the casting. Consequently, we continue drying until we have the temperature, or at least the depth of penetration of the heat, necessary to dry the mold so the cores may be set.

MR. APPELBY: Do you make any provision for taking moisture out between the cope and the pit?

MR. HAMBLEY: Yes. At all the corners where the rails are the joints are left open, but all the risers and everything on top are closed off. The only way the steam can escape is through the vents in the bottom, through the coke bed, or at the corners at the joining between the cope and the pit.

MEMBER: What is the mold hardness on a casting of that type?

MR. HAMBLEY: It is rammed as hard as we can ram it.

ROBERT LATHAM²: In coring up, do you continue to core 24 hours a day or 8?

¹ Buffalo Foundry & Machine Co., Buffalo, N. Y.

² Bethlehem Steel Co., Bethlehem, Pa.

MR. HAMBLEY: It depends upon how busy we are and how soon the customer wants the casting, but it is generally only 8 to 10 hours per day.

MR. LATHAM: If it was on an 8-hour basis, would you continue to use any additional heat in the mold, or do you stop your heat off entirely?

MR. HAMBLEY: Once the heat is discontinued, the mold is finished so far as heat is concerned. The only heat that is used is when we mud up certain hooks, cores and eyes, and build a little charcoal over them. In cases of over 5 days' drying, we find the mold is practically completely dry.

MR. LATHAM: I assume the casting weighs between 100 and 150 tons.

MR. HAMBLEY: Around 100 tons, but the one in particular that I started to sketch was in a pit 38 ft. long and it weighed 71 tons. It took 140,000 lb. of metal to pour.

MEMBER: What is the pouring temperature?

MR. HAMBLEY: On that kind of casting, it depends on the type of metal. On high test iron, with a guarantee of 50,000 p. s. i., we pour at a minimum of 2500°F. Some of the other castings, requiring only a common grade of iron, are poured much colder, at 2380 or 2400°F.

MEMBER: Why do you locate the pattern originally in the pit so far below the coke surface?

MR. HAMBLEY: We illustrated only the bottom section of the pattern in Figs. 2 and 3. There are probably two other sections of the pattern that come in on top of it and are built up. If the pattern is in sections, the bottom section is located first to start the ramming. In most cases, we can use an air hammer to ram the facing against the pattern to make sure it is hard.

MR. APPELBY: Have you experimented on or arrived at any definite depth of drying large, heavy castings, consistent with foundry practice?

MR. HAMBLEY: The whole process depends entirely upon how long it is going to take to core up. We dry some molds just one night, and we dry others for a few days. If the job can be cored out and poured off in one day, it need not be dry more than about 2-in. from the face. If it is going to take a week, greater depth is needed, and if it is going to take three weeks, the mold has to be practically completely dry. We know from experience that in pouring small castings on a conveyor, we skin dry the mold and then pour inside of 20 min. This is on the same basis.

MR. APPELBY: On jobs that require 2 or 3 weeks to core up, have you found, with shorter drying periods to get a penetration of, say, 2, 3 or 4-in., any evidence of moisture working back through the surface?

MR. HAMBLEY: If we made a miscalculation like that and dried a pit, say, 4-in. back, and took three weeks to core it up, we would certainly look for a scabby casting.

MR. APPELBY: We do a class of work very similar to what you have described. We had to conduct quite a number of experiments to find out just how deep the penetration should be to secure good results. We have many jobs that take 2 or 3 weeks to core up. I have found that if we can dry to a depth of 4-in., we never have any trouble. In fact, with our dry-

ing methods, we do dry to 4-in. in a maximum time of 24 hours. We dry pits 40 ft. long, 15 ft. wide and 8 ft. deep in 24 hours at 450°F.

MR. HAMBLEY: That is certainly interesting. Just this year we have started putting thermocouples in the mold to learn what actually takes place, and probably we will find out the same thing, although having the benefit of your experience, we will probably go a little faster now.

MR. APPELBY: It is just a matter of whether it is necessary to go beyond a certain point. If the job can be done with, say, 4-in. of penetration, why go deeper?

Teaching Foremen to Teach

BY WM. ODOM*, CHICAGO, ILL.

1. In spite of all the diagrams of the foreman's responsibilities and duties, it seems that he is the fellow to whom are delegated all the jobs management does not want to do. In beginning to "train" foremen, it must be recognized that they have been doing a good job thus far.

2. It is not necessary to send a foreman through college to help him do a better job of training. If the foreman cannot be helped in his training efforts by group meetings in the plant, the meetings have been poorly prepared. It is important to know ahead of time what objective the group should reach at these conferences. If it is a problem of production, it should be worked out with management first to establish the proper engineering procedures and principles and then the foreman should be asked to express his ideas. If it is a question of labor relations, it cannot be done properly without giving the foreman some conception of present-day labor conditions. It is surprising how few foremen know much about the new regulatory laws. After they have been explained, the foremen are in a position to arrive at some of the answers to the problems the laws create.

3. The foreman is expected to train new people, so some time and effort should be given to teaching the foreman to teach. The following outline shows the present-day concept of teaching as it affects the foreman in any kind of a plant:

- I Find out what it is the *man* needs in order to do *his* job properly
 - A. Analyze the job
 - 1. Physical effort
 - 2. Mental effort
 - 3. Skill
 - 4. Responsibility
 - B. Study the man
 - 1. Social values
 - 2. Mechanical values
 - 3. Mental values

* Wm. Odom Associates.

NOTE: This paper was presented before the Foreman Training Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

4. Physical values
 - C. Compare A and B
 - D. List differences or deficiencies
- II Give the man what he needs in order to do his job properly
- A. Break down deficiencies into series of units or lessons
 - B. Arrange these units in order of learning difficulty
 - C. Use a definite teaching technique
 1. Preparation
 2. Demonstration
 3. Application
 4. Examination

4. If a general training program or curriculum is laid out in advance, it will be found that it is geared too fast for some or too slow for others. An individual training schedule should be made up for each person.

5. To find out what a man needs to do his job properly, first, analyze the job. Practically every job can be broken down into four fundamental factors, namely, physical effort, mental effort, skill and responsibility. A description of the job to be taught should be made from the standpoint of these factors, each of which will vary in a number of ways.

6. When a fairly complete description of the job has been worked up, the individual should be studied and a conscious effort should be made to determine his assets. When this has been done, compare his assets with what the job requires and list his differences or deficiencies. This will show what he needs in order to do his job properly. Arrange these deficiencies into a series of units or lessons in order of learning difficulty, and, finally, use a definite teaching technique.

7. The first step should be the preparation of the individual for his instruction. Then, an explanation should be given of what is to be done and a demonstration should be put on at the same time the job is being explained. The third and most important step is application, letting the man learn the job while he does it himself, thereby giving the instructor an opportunity for an examination.

8. Restore the foreman's prestige by giving him more knowledge and equipment to do his managerial job, and he, in turn, will begin to command the respect that he has lost in the last few years.

DISCUSSION

Presiding: W. E. GEORGE, Campbell Wyant & Cannon Foundry Co., Muskegon, Mich.

Co-Chairman: G. J. LEROUX, National Malleable & Steel Castings Co., Cleveland, O.

MEMBER: How many of us here are in a position to put such a plan into effect? How can we get this information across to our management?

CHAIRMAN GEORGE: Regardless of your job, if you are a good salesman, you can bring this information to the attention of your management and make them realize the value of and the need for this training.

MEMBER: To convince our management that we wanted a training program, we started our own, meeting after hours on our own time. Each one of us took turns presenting a paper to the rest of the group. Out of 300 foremen in the plant, about 50 or 60 would turn up for the meetings. When the management saw that we had a training program they took an interest in it. I believe the foremen must first prove to management that they want training.

MEMBER: In setting up our foreman conference group, we got the idea that there were men in the shop who did not know what the other man's job was or what he did. We wrote up discussions on about twelve jobs in our own plant. For instance, we selected the open-hearth furnace as one discussion subject and had the head melter discuss it. We believe it is a good idea to get someone in the plant who knows everything about his own job to explain it to the rest of the men.

MEMBER: There are a great many vendors who have educational literature, such as motion pictures, booklets, etc. who would be glad to come to a plant and explain a certain machine or material.

Report of Steel Division Committee on Magnetic Powder Testing

The Steel Division Committee on Magnetic Powder Testing was organized in October, 1941, for the purpose of summarizing the information available on this type of non-destructive testing. The Committee has encountered considerable difficulty in gathering definite information concerning the use of the method on production castings. This has been due to the fact that at the present time the method is used primarily by government inspection agencies on ordnance or other castings, upon which publication of information is restricted.

The information given below, therefore, is only an introduction to the subject. It is advisable to introduce any comparatively new subject with a few fundamental principles and definitions in order that the discussion may be based on common terms.

DEFINITIONS

(1) *Magnet*—A magnet is a piece of material which has the property to magnetize and attract ferromagnetic substances such as iron, steel, cobalt and nickel. A magnet has at least two poles, commonly called the North and South poles due to tendency of magnetic materials to align themselves with the earth's magnetic field and point to the earth's North and South magnetic poles.

There are two types of magnets, as follows:

(a) *Permanent Magnets*, which may occur in nature, such as the mineral magnetite, or which may be produced artificially by magnetizing a hardened steel or some special alloys.

(b) *Electromagnets*, which are made by surrounding an iron core by a coil winding through which an electric current is passed. Electromagnets are magnetic and will attract ferromagnetic materials only while a current is flowing through the winding. A common example of this type of magnet is the lifting magnet used in moving magnetic materials in the foundry.

(2) *Magnetic Materials*—The strongly magnetic materials are those mentioned previously: Iron, steel (except austenitic steels), cobalt and nickel, and special alloys of these constituents. The soft steels and irons cannot be permanently magnetized, but they will

NOTE: This report was presented before a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

assume the characteristics of a magnet when they are used as the core of an electromagnet or when they are near or in contact with any magnetizing force, such as an electromagnet or permanent magnet.

(3) *Magnetic Field*—This is the name given to the space adjacent to the pole of a magnet. All magnets have polarity, and like poles will repel each other, while unlike poles will attract.

(4) *Lines of Force*—Lines of force are the physicist's means of representing a magnetic field diagrammatically. It should be understood that they are used only as a means of explaining magnetic phenomena and that they do not really exist as "lines of force."

(5) *Retentivity*—This is the property of retaining magnetism. As noted previously, the hard steels and special alloys have a high retentivity and will remain permanently magnetized. The soft steels and irons have low retentivity and lose their magnetism as soon as the magnetic field is removed.

(6) *Longitudinal Magnetism*—The simplest example of longitudinal magnetism is the ordinary bar magnet, with its North and South poles and the return path through the air. The usual method of producing longitudinal magnetism is by inserting the piece, or part of it, in an energized coil or solenoid.

(7) *Circular Magnetism*—Circular magnetism may be induced by the passage of current through or near the piece or, in the case

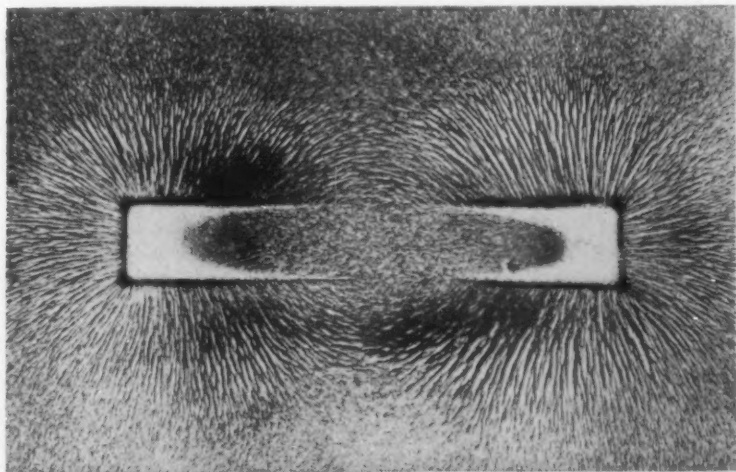


FIG. 1—BAR OF HIGH CARBON MAGNET STEEL, ONE-IN. SQ. AND 6 $\frac{1}{2}$ -IN. LONG, MAGNETIZED IN THE YOKE. PATTERN OBTAINED BY SIFTING IRON FILINGS THROUGH 100-MESH SIEVE ONTO WHITE PAPER.

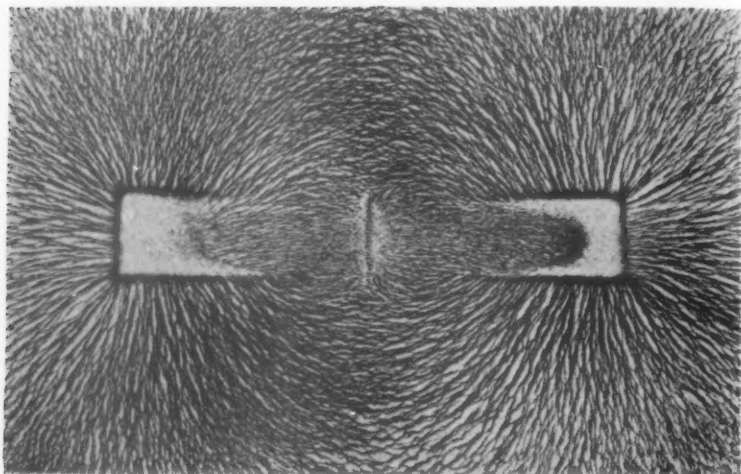


FIG. 2—SAME BAR AS THAT SHOWN IN FIG. 1, CUT IN THE MIDDLE.

of a hollow cylinder, by passing an energized conductor through the bore. If a current is passed through a copper wire, a magnetic field will be created around the wire. If the wire were to be grasped in the right hand with the thumb extended in the direction in which the current is flowing, the fingers would indicate the direction of the "lines of force." The magnetic field would be indicated as moving from the palm of the hand through the fingers.

If the wire were to be placed in the center of a ferromagnetic cylinder, a magnetic field would be induced in the cylinder, revolving on a closed circular path. Similarly, if a current is passed through a ferromagnetic rod a circular magnetic field would be induced in the rod.

With this type of magnetism the flux is considered to pass in a continuous circle with practically no external field and no noticeable polarity.

(8) *Consequent Polarity*—Consequent polarity describes the condition when more than two poles are present. For example, a bar magnet magnetized in such a way that there is a North pole at each end of the bar and a South pole in the center of the bar is said to have "consequent poles."

MAGNETIC TESTING

The principles employed in magnetic testing may be explained by using these simple definitions. Let us start with a simple bar

magnet. If we note the direction of the "lines of force" by that simple experiment used in elementary physics and place a piece of paper over the magnet, sprinkle iron filings on the paper, and then tap the paper slightly, we find the "lines of force" radiating from each pole with the greatest mass of filings concentrated near the poles as shown in Fig. 1. If we break this magnet in two and repeat the experiment, we find that each piece now has a North and South pole and that a mass of filings has collected at the "break," illustrated in Fig. 2.

This experiment may be repeated many times and in each instance the piece broken off will contain its North and South poles. The pieces pushed together will exhibit "consequent poles" when tested with iron filings, and the "break" will in each case be indicated by a concentration of the iron filings.

Circular Magnets

If we should take a bar magnet and bend it into a circle and use filings to indicate the field, we would again find a concentration of filings at the two poles which have been brought near each other. It is obvious that the conditions produced by a bar magnet bent into a circle can also be produced by merely cutting a slot through a

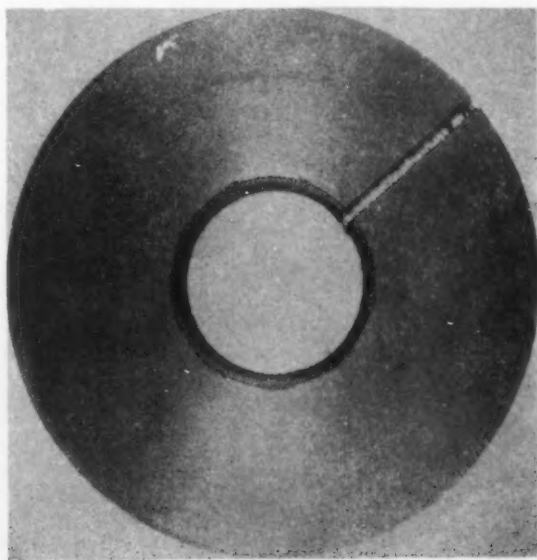


FIG. 3—PIECE OF HIGH CARBON TOOL STEEL $2\frac{1}{2}$ -IN. DIA., $\frac{3}{8}$ -IN. THICK, ONE-IN. DIA. CENTER HOLE, WITH $\frac{1}{16}$ -IN. SLOT SIMULATING CONDITIONS OF A CIRCULAR MAGNET.

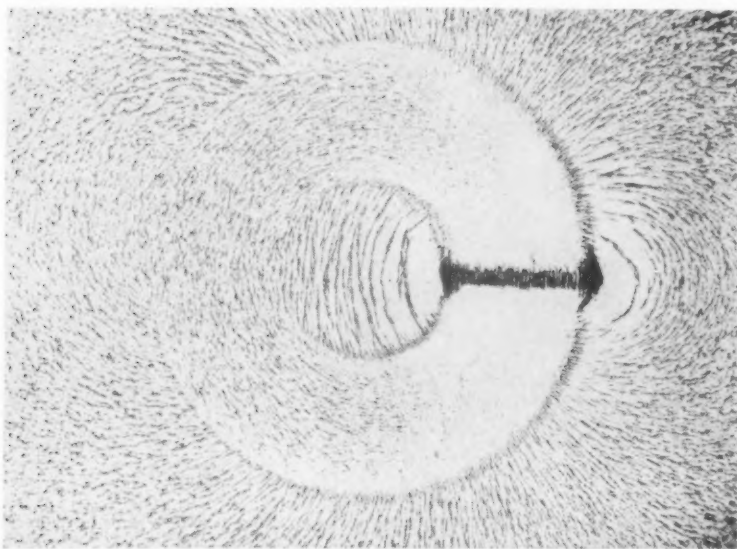


FIG. 4—SAME PIECE AS SHOWN IN FIG. 3, MAGNETIZED IN THE YOKER, COVERED WITH WHITE PAPER AND IRON FILINGS SIFTED ON AS IN FIG. 1.

cylinder magnetized circularly, by passing a current through a wire at its center. This is shown in Figs. 3 and 4.

In the solid cylinder the flux flows continuously and, as stated previously, there is no appreciable external field and no noticeable poles. Once this continuous circular flux path is broken by a slot, we have two poles and flux leakage, conditions similar to those created by bending a bar magnet into a circle.

Similarly, if we cause a break in the circular flux lines of a circularly magnetized solid bar, we again create local poles or local flux leakage which can be indicated by the use of iron filings as in our simple experiment with the bar magnet, illustrated in Figs. 5, 6, 7 and 8. These local poles or local flux leakages will occur wherever there is an abrupt change in the magnetic permeability of the test piece. Thus several slots in the circularly magnetized bar will produce a series of consequent poles, each of which can be detected by the same means.

Special Powder Test

All of the illustrations shown so far have been produced by shaking iron filings on a piece of white paper, placed over the magnetized piece. Figure 9 was obtained by using a light colored

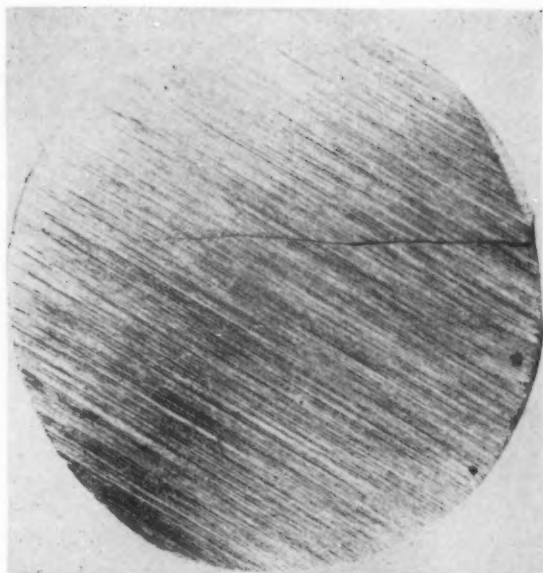


FIG. 5—A CYLINDER OF HIGH CARBON TOOL STEEL 2-IN. DIA. x $6\frac{1}{2}$ -IN. LONG, CRACKED IN QUENCHING. SPECIMEN WAS PLACED BETWEEN COPPER PLATES AND 500 AMPERES PASSED THROUGH IT WITH A WELDING MACHINE.

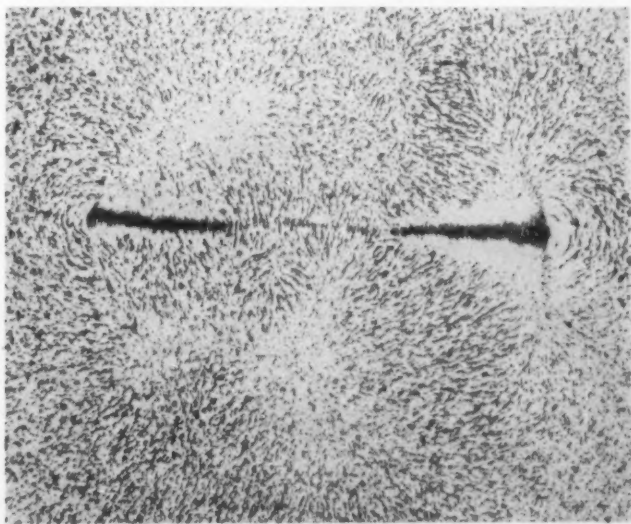


FIG. 6—SAME CRACK SHOWN IN FIG. 5 AS REVEALED BY USE OF WHITE PAPER AND IRON FILINGS.

powder especially prepared by this type of testing on the specimen illustrated in Figs. 7 and 8. It is interesting to note that an additional portion of the crack is revealed by using this type of powder.

It is not necessary to have an actual slot or crack to produce these local poles. They may be caused by the presence of non-metallics such as sand, slag, etc., or by an abrupt change in the permeability of the material caused by variations in heat treatment, high stresses, etc.

Basic Test Conditions

To summarize, two basic conditions are required in this type of magnetic testing:

(1) An abrupt change in the permeability within the path of magnetic flux flowing through a magnetized piece of material which produces local poles or local flux leakage.

(2) A method of detecting these local poles. This condition is satisfied by the use of finely divided ferromagnetic powders which offer a lower reluctance path than a liquid or air and hence tend to gather in the leakage field and thus define the outline of the field.

Every testing method has its limitations and variations which must be taken into account. This method of inspection is no exception. It is, of course, applicable only to magnetic materials. Alloys which are only faintly magnetic do not produce satisfactory results.

Magnetic Discontinuities

Defects in material tested by this method produce magnetic discontinuities. Magnaflux testing outlines these discontinuities. The outline produced by the powder is called an indication. It should not be assumed that all indications are the result of defects. The shape of the magnetic discontinuity is most important. Best results are obtained when the magnetic discontinuity cuts the "lines of force" at a 90 degree angle. Long, narrow discontinuities parallel to the "lines of force" give very poor indications or none at all.

It is evident that magnetic discontinuities near the surface will be detected readily, whereas magnetic discontinuities lying below the surface will have diffused leakage fields which result in diffused outlines difficult to interpret.

Porosity can be detected when it is near the surface and in deeper locations where the cavities are large and few in number. If deep-seated porosity is composed of a large number of small holes, the possibility of detecting it is slight.

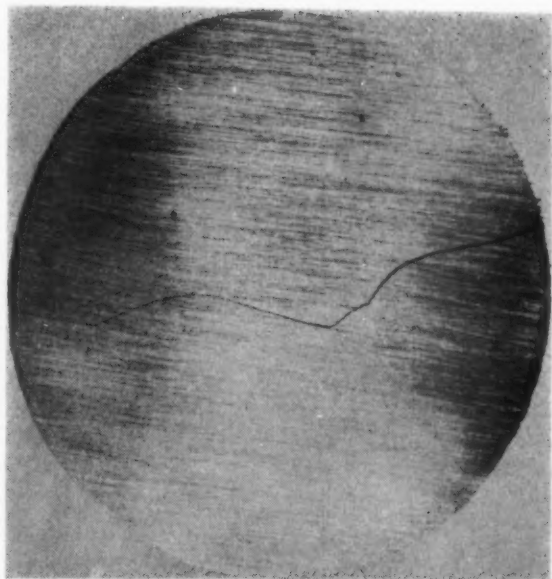


FIG. 7—OPPOSITE END OF SPECIMEN BAR ILLUSTRATED IN FIG. 5.

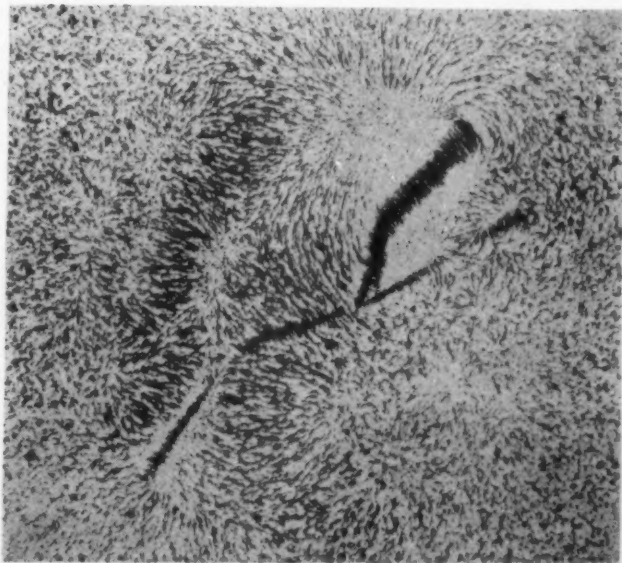


FIG. 8—SAME CRACK AS SHOWN IN FIG. 7 AS REVEALED BY USE OF WHITE PAPER AND IRON FILINGS.

In all cases, the outline of the magnetic discontinuities and the depth at which magnetic discontinuities can be found will be dependent upon the strength of the leakage field present. This is dependent upon the shape of the piece under test and the strength of the magnetizing force.

METHODS OF MAGNETIZING

Magnetic tests may be conducted by using residual magnetism in a previously magnetized piece, or by the so-called continuous methods where the powder is applied while the test piece is under the influence of the magnetizing force. The latter method is preferred for the low carbon steels and only this method will be discussed here.

The type of magnetization desirable will depend upon the material to be tested and the location where the test is to be made. The following remarks, therefore, are general in character and will not apply to all conditions. The three methods which are found in common practice are the use of the test piece itself as the conductor (direct method), the use of the magnetic yoke (indirect method), and the use of the solenoid (indirect method).

The "magnetic yoke" is merely an electromagnet of the horse-shoe (or modified horseshoe) type. The two poles of the electromagnet are placed on the test piece, the magnetic circuit is completed through the test piece, and the area between the poles is thus available for testing.

In the solenoid method a conductor is wrapped around the test piece. A current passing through the conductor will magnetize the piece by induction.

For long slender pieces both the solenoid and "direct" methods may be employed to insure a complete examination of the piece.

The magnetic yoke is usually used only on pieces which are difficult to test with either the direct or solenoid methods, as this method is not as sensitive as either of the other methods.

Direct current is usually used but alternating current is suitable for some types of tests. Alternating current may also be used with proprietary equipment which converts it to broken alternating current or pulsating direct current, which produce satisfactory results.

The direct current required may be used at any line voltage for magnetic yokes, but a low voltage-high amperage current is desirable when the test piece is to be used as the conductor. Current

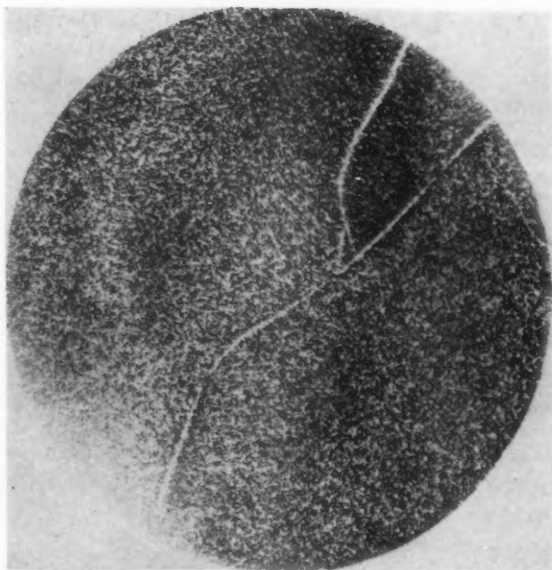


FIG. 9—SAME CRACK AS SHOWN IN FIG. 7. IN THIS CASE, NO WHITE PAPER WAS USED. INSTEAD, MAGNAFLUX POWDER WAS EMPLOYED IN PLACE OF IRON FILINGS. SINCE THE MAGNAFLUX POWDER IS LIGHT IN COLOR, IT WAS NECESSARY TO TURN THE PIECE SO IT DID NOT REFLECT TOO MUCH LIGHT.

of this type may be obtained from storage batteries or motor generator sets. A modern welding generator may be used in many instances.

INSPECTION MEDIUM

The powder to be employed should have the following characteristics: (1) High permeability, (2) low coercive force, (3) low retentivity, and (4) good mobility.

After properly magnetizing the part, the powder may be applied by either of two methods, commonly called "dry" method and "wet" method. For either method, proprietary powders of the proper size and shape are available, which have colored coatings to increase the contrast with the background and thus facilitate testing. Other powders, which are not of a proprietary nature, also have been used and gave satisfactory results.

The powders used for the "dry" method are usually treated to increase their mobility and prevent agglomeration. The powder may be applied from a hand-shaker, bulb-blower or mechanical

blower. The use of the hand-shaker is limited to nearly horizontal surfaces, whereas the blowers may be used on vertical or overhead surfaces.

In the "wet" method the powder particles are suspended in liquids such as kerosene, gasoline or carbon tetrachloride. A fire hazard is sometimes involved which requires the use of carbon tetrachloride and, if used, ventilation must be provided, as the fumes are poisonous. The liquid can be sprayed or flowed over the part to be inspected; if flowed, care should be exercised so that potential indications are not washed away by the force of the stream.

SURFACE PREPARATION

The surface is important in this type of testing. In general, the smoother the surface the better the results will be. In examining rough castings, careful interpretation of the results is essential, as many minor surface imperfections may appear to be serious defects. All heavy layers of rust, scale and grease should be removed prior to testing. Thin, even layers of rust or scale will not cause much difficulty.

DEMAGNETIZATION

Demagnetization is an important consideration in some applications. There are many methods which may be employed and the subject should be studied thoroughly if demagnetization is required. The simplest method which is applicable in many installations is a large alternating current solenoid through which the pieces may be passed and slowly withdrawn.

Demagnetization is not required at all if:

- (1) The piece is to be heat treated at a temperature high enough to cause demagnetization;
- (2) The piece has low retentivity. (This includes all low and medium carbon steels and some low alloy steels);
- (3) The piece is to be magnetized in final assembly.

As previously pointed out, all magnetic indications do not represent material defects. Therefore, results should be clearly interpreted to be of value. The approximate location, number and size of indications should be reported and described as fully as possible. Cracks, porosity, inclusions, etc. should also be identified. This

information, together with the service requirements of the part, must be considered when the acceptability or repair of a part is subject to question.

Respectfully submitted,

COMMITTEE ON MAGNETIC POWDER TESTING

R. A. Gezelius, *Chairman*

T. N. Armstrong,

A. P. Spooner,

J. A. Duma,

W. J. Phillips.

Government "Training Within Industry" Program

BY O. F. CARPENTER*, DETROIT, MICH.
INDUSTRY REPRESENTATION

1. In establishing the Training Within Industry program, it was decided that it should be distinctly connected with industry. Therefore, when the original committee was set up, it consisted of Messrs. C. R. Dooley of Socony-Vacuum Oil Company, J. Walter Dietz of Western Electric Company, Wm. Conover of United States Steel Corporation, and M. J. Kane of American Telephone & Telegraph Company, each one representing a particular branch of industry.

PURPOSE

2. The Training Within Industry program was established for one purpose, namely, to assist the contractors or anyone in war production in solving their manpower problems. For example, the people in Detroit who had been building automobile bodies for years conceived the idea that they might be able to build aircraft by exactly the same procedure. Immediately upon getting the contracts, they discovered that there was considerable difference between building planes and building automobile bodies. It meant that they had to start from "scratch" and train a lot of people to build aircraft who had been previously building automobile bodies. They discovered that even though they had held within very close limits for a good many years in building motors and motor cars, etc., the limits would be a lot finer in war production.

ORGANIZATION

3. The Training Within Industry Committee has divided the United States into 22 districts. Each district has a man assigned to it who is known as the district representative. That representative is taken from industry on the basis of acquaintanceship within the area and organizational ability and is assigned the job of setting up an office and hiring the necessary personnel to carry out all the functions of the Training Within Industry program for his district. The office is set up in close connection with the War

* Associate District Representative, Michigan Area, Training Within Industry Committee.

NOTE: This paper was presented before the Apprentice Training Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

Production Board, including contract service, priorities and labor supply. Twelve to 20 men are selected from the plants in the area, representing the industry generally, and they are called panel consultants. They are the key men in the district and are sent out to the plants when it is necessary to help establish the plant to meet contracts.

ACTIVITIES

4. The Training Within Industry program at the present time is not a policy-making program. It does not determine how hiring is done, how many are hired, when they are hired nor what kind of collective bargaining agreements are made. It is a practical, advisory service, dealing with training methods and procedures. It disseminates the latest information based on current practices in industry. This information is pooled in such a way that we can draw it from all of the 22 districts, and supply the latest information from any organization that is doing a training job.

5. The Training Within Industry program is concerned only with workers who are on pay rolls where training is carried out on the job, within the plant, and the workers learn by doing and produce while they learn.

6. We have found that we can train an operator in about 10 hours of intensive job instruction. We not only provide the instruction but also the instructors who do the job directly in the plant. The instructors teach the workers how to instruct other men to do the job. These instructors are selected from the staff and are sent out at no cost to the plant. No Training Within Industry representative can go into a plant in any area without an invitation. It is a purely voluntary service.

7. We show employers how to get skilled operators from all grades of workers by handling, analysis of jobs and intensive instruction. Obviously skilled foundrymen or patternmakers cannot be made in any less time than the eight thousand hours established for skilled men, but we can do other things that will help.

8. The main function of the Training Within Industry program is its aid in the practical plan for upgrading workers to higher skilled jobs as rapidly as their ability warrants, so that new people can be brought in at the bottom. It is no longer possible to hire skilled people, so the next best thing is to upgrade people in lower skill jobs, inventory them as to capability and move the best

into the next bracket, with a strict disciplinary course of ten hours job instructor training, so they can instruct other workers to do simple jobs.

9. The services of the Federal Committee on Apprenticeship are closely related to the in-plant Training Within Industry activities for the rapid development of all-around skilled craftsmen. We work closely with this committee which is represented in every district by panel consultants. Whenever apprenticeship is considered, the Federal Committee on Apprenticeship helps us to establish labor standards and answers questions for us.

The program works for closer cooperation of the local schools and other agencies training workers for present jobs and advises industry as to where help and supplementary training can be secured, if necessary.

LABOR AND MANAGEMENT ADVISORS

It is backed by management and labor. An advisory committee of eight people, four representing labor and four representing management, was set up in Washington when the program was established. The main function of the advisory committee is to see that anything set up in a Training Within Industry program does not conflict with labor or management. We have labor advisors in every district who go over our programs with us and talk before factories and plants. The Training Within Industry program is now recognized by labor as one of the essential things.

We believe that anyone, whether he is operating a large plant or a small plant, can profit by some suggestion, advice or help from the Training Within Industry program.

A Foundry Investigation of Bond Clay Properties

By A. S. NICHOLS*, F. W. HINTZE*, AND F. L. OVERSTREET*
CHICAGO, ILL.

INTRODUCTION

1. Since the early 1920's, when molding sand reclamation and the manufacture of clay-bonded molding sands were first used, the evaluation of different clay bond materials has been a subject of controversy.

Requirements of a Clay Bond

2. The requirements of a satisfactory clay bond seem simple—

- (1) It must not introduce sand properties which will hinder reproduction of good sound castings which can be economically cleaned.
- (2) It must bond the new and reclaimed sand grains to a green strength capable of making a mold at the least possible cost per ton of castings.
- (3) It must not introduce sand properties which make for excessive cost in mold-making and sand-handling.

3. A properly tempered sand may be bonded to the correct strength and possess all of the other physical characteristics necessary to produce a good casting. The first castings poured may be perfect; yet, every foundryman knows that with continued use of any sand, the heap or unit sand undergoes changes that materially affect the castings produced. Obviously, therefore, a choice of clay bond cannot be made solely on the basis of the properties of the newly bonded sand and the castings it first produces.

4. It is equally well-known that, while measurement of the amount and cost of bond required to produce a certain green strength in the sand will provide a basis for evaluation of different bonds, this cost factor may be radically altered by the burning out of the bond or by the degree to which it causes the sand to adhere to the casting and be carried away.

* Vice President, Sales Engineer and Foundry Engineer, respectively, Illinois Clay Products Co.

NOTE: This paper was presented before a Foundry Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, Ohio, April 22, 1942.

5. As for the third requirement, it is also a well-known fact that flowability, shake-out, and other sand-handling characteristics are frequently altered in use.

6. The so-called durability test, designed to approach the subject in the manner previously indicated, was first used by several of the larger production foundries, beginning about 1927, and first published by M. A. Blakey¹, International Harvester Company. Most tests of this nature did not attempt to go far into the quality of casting produced and usually were concerned primarily with the real cost of different bonds, using a sash-weight-type casting to break down the sand by continued use.

7. A Subcommittee on Durability was appointed by A.F.A., in 1930, and its efforts have been largely concerned with devising a method to determine durability. The subject was reported on exhaustively in 1937 by C. E. Schubert², who investigated the effect of a mold test of the slug type, as well as two short-cut methods, an "oven test" and a "hydration and dehydration test." His report was without reference to casting quality, and the physical test data on the synthetic sands were based on only two clays, a bentonite and a kaolinite. Sea coal which is used in many foundries was omitted from the mixtures used.

8. Several foundries in the automotive, tractor or implement groups, particularly, have made extensive "use" tests of different clays with interesting and, for the most part, valuable data obtained on both sand properties and castings quality. The many foundry variables existing on such large-scale tests have been almost impossible to control, and while "trends" frequently have been indicated, accurate conclusions have been rare.

9. As the authors frequently are confronted with engineering problems that arise from circumstances beyond the limit of clearly acceptable facts of evaluation, they believed it worth while to carry out a practical investigation of commonly-used bonding clays to answer some of those questions which arise constantly. Accordingly, a test procedure was devised in which molding sands were made containing respectively each of the commonly-used clays as a bonding agent. The sands were held to uniform green strengths and contained sea coal in commonly-used proportions. Molds were made from each of these molding sands and poured. Instead of the so-

¹ Blakey, M. A., "Testing Molding Sands for Durability," TRANSACTIONS, American Foundrymen's Association, vol. 36, pp. 1-12 (1928).

² Schubert, C. E., "A Correlation of the Physical and Chemical Properties of Clays with the Durability of Molding Sands," TRANSACTIONS, American Foundrymen's Association, vol. 45, pp. 661-690 (1937).

called slug-type bar, a specially-designed casting, which would be subject to a large number of defects commonly attributed to sand, was used. The operation of molding and casting was repeated over and over again, exactly as in production, but with all conditions approaching laboratory procedure in accuracy.

LOCATION OF TEST AND EQUIPMENT USED

10. The cooperation of Western Foundry, Chicago, was obtained, and a section of one of their foundries set aside for the work. The following equipment was purchased:

A. Portable sand testing equipment, including:

- (1) Two sets of balances.
- (2) Rammer, with flowability meter.
- (3) Permeability meter.
- (4) Universal strength machine.
 - a. With compression and shear attachments.
 - b. Deformation indicator.
- (5) Moisture teller.
- (6) Thermostatically controlled drying oven.
- (7) Laboratory size, muller-type mixer.
- (8) Mold hardness tester.
- (9) Stop watch.

This testing equipment was built into a composite, portable frame.

- B. Four-foot muller-type mixer.
- C. Jolt squeeze molding machine with 10-in. cylinder, equipped with automatic blow-off and pressure gauge.
- D. 500 lb. capacity platform scale.
- E. 20 lb. capacity parcel post scale.
- F. Two 9 x 12 ft. congoleum rugs.
- G. Five sealtite steel drums.
- H. One 16 x 23-in. slip flask.
- I. Five 16 x 23-in. mold jackets.
- J. Three 14 x 21-in. mold weights.
- K. Five 16-quart excess sand containers.
- L. One 40-in. long, 20-in. wide, 21-in. deep shake-out box.
- M. Five 24 x 16-in. shake-out pans.
- N. Miscellaneous scoops, liquid measures, brushes, two-quart sealed jars, etc.
- O. Optical pyrometer.

CHOICE OF MOLDING MATERIALS

Base Sand

11. No. 50 Ottawa silica sand was chosen as a base, principally because of its uniformity which completely eliminated any variable in sand additions. Its screen analysis follows:

	<i>Per Cent Retained</i>
On 40 mesh	0.2
On 50 mesh	12.5
On 70 mesh	37.6
On 100 mesh	37.8
On 140 mesh	9.5
On 200 mesh	1.8
On 270 mesh	0.4
Pan	0.2
A.F.A. Fineness No. 63.7	

This is somewhat finer than the new sharp sands most frequently used in automotive gray iron practice, which will range from A.F.A. Fineness No. 35 to No. 55, but the permeabilities with this sand are about the same, due to the better grading in the coarse and fine brackets.

Sea Coal

12. A sea coal recommended by the producer, for use with the base sand used, was chosen. It analyzed as follows:

	<i>Per Cent Retained</i>
On 40 mesh	12.7
On 50 mesh	10.2
On 70 mesh	10.2
On 100 mesh	13.5
On 140 mesh	11.7
On 200 mesh	10.4
On 270 mesh	14.2
Pan	17.1

Other specifications on the sea coal used were:

Ash content	less than 8 per cent
Volatile	33 per cent
Sulphur	1.5 per cent

Clays

13. The clays chosen for investigation were as follows:

<i>Mark</i>	<i>Type</i>
A	Illite
B	Western Montmorillonite
C	Southern Montmorillonite
E	Kaolinite

Originally two different kaolinite type clays were included, but their properties were so similar that, for the purpose of simplification, only one is included herein.

SAND SPECIFICATIONS

14. Two hundred pound batches of sand were used, bonded to a 10 lb. per sq. in. green compression strength, with moisture added to temper. A 6 per cent sea coal content was maintained.

PRELIMINARY PROCEDURE

15. After determining the amount of each clay required to obtain a 10 lb. per sq. in. green compression strength sand, through the use of dummy batches, a full-scale operating cycle was then repeated 20 times, producing 100 castings, to eliminate variables not immediately apparent. This first run brought to light many factors of importance used to establish the final operating routine.

OPERATING ROUTINE

16. The operating routine proceeded as follows:—

A. Sand Preparation and Testing.

- (1) Prepare 200 lb. batch of sand (dry weight)—mulled 2 min. dry, moisture added to temper and mulled 5 min. wet (standard A.F.A. procedure).
- (2) Remove 2-quart, sealed-jar, samples of sand for completing all tests, including moisture, permeability, green compression and green shear strength, deformation, flowability and dry compression and dry shear strengths. A small sample was also taken to a commercial laboratory for analysis in maintaining sea coal content.
- (3) Remove sand from muller, weigh, and place in steel drums.

B. Molding.

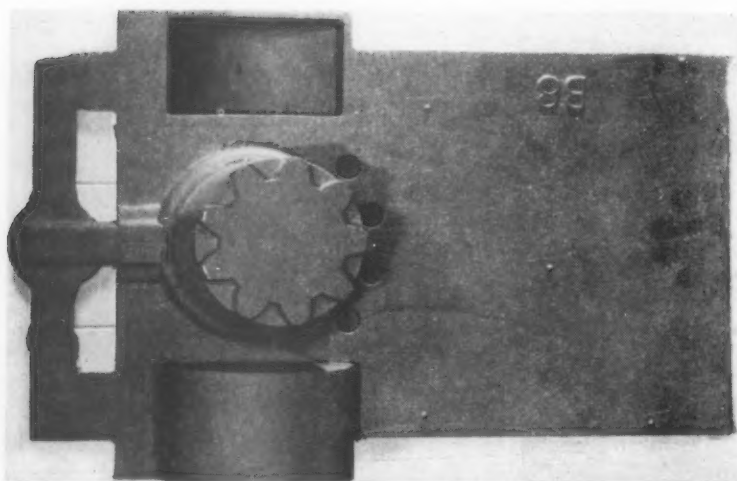


FIG. 1—HOUSING TYPE CASTING USED FOR STUDYING CASTING DEFECTS IN RELATION TO SAND PROPERTIES, AS INFLUENCED BY USE OF DIFFERENT CLAYS.

- (4) Fill all molds to same level, so there will be equivalent volume affecting the jolting and squeezing of the mold. Count all jolts and hold at 20. Squeeze to 80 lb. per sq. in. pressure. No hand peening, slicking, etc.
 - (5) All information recorded on the molding routine which might bring about variations in the casting finish or defects.
 - (6) Mold-hardness readings taken and recorded from nine locations on the cope and seven locations on the drag.
 - (7) Cope and drag sections of the mold weighed to record weight of sand in mold, for sand to metal ratio.
 - (8) All sand spilled during each molding operation collected and placed in small excess sand containers to prevent loss.
- C. Pouring.
- (9) All molds poured from the same transfer ladle. Temperatures not always obtained at the mold but more frequently at the cupola. A comparatively short transfer from the cupola enabled maintenance of uniformly hot pouring tempera-

tures. Hand ladle was relined every day, and care was taken to see that it was clean and dry. Average pouring time about 6 sec.

D. Shake-out.

- (10) All molds permitted to stand for one hour before shaking out. Entire mold, jacket and bottom board were transferred to shake-out box to eliminate all spillage and loss of sand. Jacket and bottom board were then removed, after which the casting was suspended on a shake-out hook and given 15 raps with the hammer.

E. Cleaning.

- (11) After shake-out, the castings were each placed on a shake-out pan and weighed. Each day's operations were concluded at this point. The sand which remained on the casting and in the pockets was then cleaned off by hand brushing, the next morning. The castings were then weighed again. The difference in these two weights used to indicate the amount of sand that could be carried out on castings in regular production. This can be a heavy expense if dry strengths are not controlled. There is not only a disposal cost and new sand grain additions, but also a loss of good moldable sand with bond and sea coal in it.
- (12) The return shake-out sand, including that from the shake-out box and from the hand-cleaning, was placed in its regular barrel for use on succeeding heats.
- (13) Shake-out sand, from the individual barrel, was weighed and placed in the muller. Each sand mulled 2 min. dry and 3 min. wet, for testing to get full data on the properties after casting.
- (14) Sand from the "excess sand containers" was then added, as well as bond, sea coal and silica sand, in proportions necessary to maintain the 10 lb. per sq. in. green compression strength, the 6 per cent sea coal and the 200 lb. total weight.
- (15) The entire batch was given additional mulling of an average of $1\frac{1}{2}$ min. Cycle then repeated the same as in items 2-15, inclusive.

- (16) Castings were given final cleaning on a sand-blast table. Cope and drag sides of casting were each given 3 min. blasting, or one revolution of the table.
- (17) Castings were weighed again.
- (18) Castings were then given very thorough two-man inspection on each section to record all defects and to make comparison of the castings made in the different sands. Recording of defects made on six-page standard inspection form.

CASTING DESIGN

17. The most important and difficult decision which had to be made was, "What casting design to use." The American Foundrymen's Association Committee on Analysis of Casting Defects have listed and classified 16 casting defects, attributable to sand conditions. The objective was to incorporate in one casting, a design that set forth those conditions which would, in turn, bring about many and possibly all of these defects.

18. Many foundrymen were consulted on this subject and their ideas and suggestions were helpful, and very much appreciated. Several different designs of castings were considered including the slug type, fly wheel type, web sheave type and housing type.

19. The slug type would have been satisfactory, if durability was the only important property to be studied. An additional objective was to study casting defects in relation to sand properties, as influenced by the different clays used. The slug type would not produce the variety of conditions required.

20. There is some similarity in a fly wheel or web sheave type casting, either of which, while simple in design, is known to have caused difficulty in making. However, the principal troubles have been from scabs, penetration or fusion, with an occasional blow hole. This would not permit as complete a study of the subject as might be possible.

21. The housing type casting was considered in conjunction with the final choice. This design seemed to present the variety of conditions desired. However, it would have been possible to obtain only a 6.5 to 1 sand to metal ratio. A 4 to 1 ratio was wanted to obtain a good foundry average. The intricacies of molding were also unfavorable.

22. The design finally chosen (shown in Fig. 1), had about everything desired, and was in the medium-weight range. It had

a light section, heavy section, large flat area, sand lifts, green sand cores, etc. The casting weighed about 45 lb. and was molded, with match plate equipment, in a 16 x 21-in. tapered, slip flask, which had a 6-in. drag and a 5-in. cope. Approximately 175 lb. of sand were required per mold, which gave a 4 to 1 sand to metal ratio, with about 588 sq. in. of mold surface exposed to the action of molten metal.

23. The design chosen started with the selection of a plate $\frac{1}{2}$ x 10 x 16-in. as it was assumed that scabs, buckles and rat-tails are produced readily on a flat surface. To induce fusion or sand burn, a hub 4 x $4\frac{1}{2}$ -in. with a 9-tooth gear on the bottom, was located near one end of the plate. The center of the hub was 3-in. in from end of the plate. A projection $\frac{1}{2}$ -in. thick and 1-in. wide extended from the hub to the edge of the plate. There was a double fillet on the hub and on the projection; the objective was to create a wave in the metal as the hub filled and the metal flowed out on the flat surface.

24. To obtain the thin section, two wing pockets were added, one on either side of the plate. The deepest pocket was located in the drag and created a lift $2\frac{1}{4}$ x $2\frac{1}{2}$ x $4\frac{1}{2}$ -in. The other wing, extending into the cope, left a green sand core on the drag. This core was $1\frac{1}{4}$ x $2\frac{1}{2}$ x $4\frac{1}{2}$ -in. The metal in this thin section was $\frac{1}{4}$ -in. A green sand core, 3-in. in diameter and 2-in. long, was located in the hub on the cope side. This was intended to promote fusion, scabs or penetration.

25. Four green sand cores, $\frac{1}{4}$ -in. high, $\frac{1}{2}$ -in. diameter, were located on the drag, in front of the inner side of the hub. They were located in the path of the metal flowing out of the hub and, not being secure, it seemed they offered an ideal condition to induce floating or washing.

26. A box was located at the opposite end of the plate from the hub. The sides of the box were 1-in. high, $\frac{3}{8}$ -in. thick on three sides, and $\frac{3}{4}$ -in. thick on the other. As this box was at the opposite end from the gate, it was assumed the metal would be slightly colder and have a tendency to cause blows. This box also created a volume of hanging sand which was $2\frac{7}{8}$ x $8\frac{7}{8}$ -in.

27. The casting was so gated, that the metal flowed directly into the hub and the wing pockets, the intention being to subject the sand to severe service in this area. The mold was poured in 6.5-7 sec., which means about 7 lb. of metal per second was flowing over this area of the mold.

STUDY OF DEFECTS

28. Table 1 shows a comparison of defects for the tenth and twentieth heats. These two heats were selected, as it was assumed that any changes in the characteristics of the sand would have occurred by the tenth cast and, if there were any further changes in the sand characteristics, a comparison of the defects shown at the tenth and twentieth heats would bring out the changes. An inspection of Table 1 shows certain defects common to all castings, regardless of the type of clay used to bond the sand.

29. It is possible, that if the molding practice had been changed for each sand, these defects would have been reduced or eliminated. Of the 16 defects listed, almost 44 per cent could have been reduced by a change in the molding or pouring operation. The defects referred to are cuts, washes, sand inclusions, crushes, swells, drops, or any defect where sand is not a major contributing factor to the defect.

Blows, Gas Holes, Pin Holes

30. No blows were obtained on any of the castings, as the permeability in all of the sands was sufficiently high to eliminate this defect.

Scabs, Buckles and Rat-tails

31. Little difficulty was experienced in producing these defects, regardless of the clay bond used. Western montmorillonite caused the most rat-tails; the kaolinite sands were second; while the illite and southern montmorillonite had the least tendency to cause this defect. The rat-tails occurred on the flat surface, while the scabs were on the curved part of the drag wing, and at the bottom of the hub core.

32. When the casting was designed, it was thought that scabbing would occur on the hub fillet, as this fillet was of a type to cause a wave in the metal as the hub filled and the metal flowed out on the flat surface. Either the sand properties were correct in all cases, or the metal section was too heavy to cause a wave, as no scabs were obtained at this location.

Cuts and Washes

33. There was considerable cutting and washing in all cases, more especially in the gate area, over the green sand cores and in the wing pocket. This defect was common to all castings, and was

Table 1
DEFECTS CHART

	A-10	B-10	C-10	E-10	A-20	B-20	C-20	E-20
1. Blows, Gas Holes, Pin Holes								
2. Scabs, Buckles, Rat-tails		X	X	X		X	X	X
3. Cuts and Washes	X	X	X		X	X	X	X
4. Sand Inclusions	X	X	X	X	X	X	X	X
5. Crushes								
6. Swells, Strains, Fins	X	X	X	X	X	X	X	X
7. Drops				X				
8. Stickers and Rats				X				
9. Ram-off				X				
10-a. Penetration (Mass)		X						
10-b. Penetration (Nigger Wool, Cat's Whiskers)		X		X				
11. Hot Cracks								
12. Run-outs								
13. Mis-runs, Cold Shuts								
14. Scars, Seams, Plates	X		X		X	X	X	X
15. Fusion—(Burning in)			X					
16. Rough Surfaces	X	X	X	X	X	X	X	X

undoubtedly influenced by the gating and speed of pouring.

Sand Inclusions

34. Sand inclusions may be found in any part of the casting. However, the sand inclusions in all cases were particularly bad in the hub area, the bottom of the drag wing in the hub core, and in the gear teeth. These sand inclusions would have been eliminated, if the cuts and washes had been stopped.

Crushes

35. Of the 100 castings made, seven showed signs of a crush on the side of the drag wing. Four of these crushes occurred in the sand bonded with the southern montmorillonite, which consistently had a low deformation value.

Swells, Strains and Fins

36. As the molder was not allowed to tuck or peen the sand, swells were obtained, particularly on the cope and drag wing pockets; also on the hub, and at the extreme end of the box. These swells were in evidence on all castings but were less pronounced on the more highly flowable illite and southern montmorillonite bonded sands.

Drops

37. There were drops in a number of cases, and the hanging sand conditions may seem rather severe in the hub core, the drag wing, and in the box. It was only with the southern montmorillonite bonded sand which had a low deformation value that any unusual difficulties with drops were experienced.

38. Some may think that, with 10 lb. per sq. in. green compression strength, there should be no difficulty experienced in holding hanging sand. This may have been true, had the molder tucked or peened the sand, which he was not permitted to do.

Stickers and Rats

39. Two castings had this defect; in both cases the sticker was between the gear teeth in the bottom of the hub; and was not noticed until the castings were cleaned. These so-called stickers may have been caused by the molder tilting the pattern while drawing it, which would have loosened the sand and caused it to wash or float.

Ram-off

40. There were no ram-offs on any of the castings made.

Penetration

41. Mass penetration was obtained on the hub core, but the only area affected on the hub was on the drag wing side where the low flowability kaolinite-bonded sands permitted a soft open ram. This could have been overcome by tucking or peening. Penetration from expansion and contraction was experienced on all sands for the first three heats, and on the western montmorillonite sand until after the fourteenth heat. After that time, there was little of this defect.

42. This defect occurred on the hub fillet. In the western montmorillonite sand, this defect extended completely around the hub. This defect also has been variously described as nigger-wool, cat's whiskers, and veining.

Hot Cracks and Hot Tears

43. No hot cracks or hot tears were obtained as the castings were all made of an iron having a normal contraction. It is entirely possible that if the castings had been made of malleable, or alloy iron, considerable trouble would have been experienced, due to too high a dry strength.

Run-outs

44. Run-outs usually are due to other than sand conditions. It is true that a sand weak in green strength, or too low in dry strength, may be a contributing factor to run-outs. In the few instances this defect was experienced, the cause was clearly one of mold jacketing. This was corrected and the defect stopped.

Mis-Runs and Cold Shuts

45. No mis-runs or cold shuts were obtained, as the molds were poured of uniformly hot iron. The pouring time varied little.

Scars, Seams and Plates

46. One casting had a defect of this nature. It occurred on the curved surface of the drag wing.

Fusion or Burning In

47. Slight burning in was experienced on the gear teeth and on the hub. This was not severe enough to cause the rejection of any

casting, as they all cleaned satisfactorily in the standard sand blast operation. The 6 per cent sea coal content gave satisfactory cleanliness.

Rough Surfaces

48. The finish of all castings was, in general, somewhat similar, excepting in those areas where the sand presented a softer mold surface. The rougher finish at these points was more noticeable in sand of low flowability. The uniform finish is largely explained by the nature of the base sand.

CASTINGS QUALITY CONCLUSIONS

49. From the foregoing, the following conclusions, with regard to quality, might be made:

- (1) There was little important difference in the quality of castings produced in sands bonded with the materials tested when the sand is controlled by proper additions and kept within desired specifications, except in the cases of the montmorillonites where the expansion-contraction properties of the western and the low deformation property of the southern variety caused defects common to these deficiencies.
- (2) When additions were discontinued the castings quality was quickly lowered in the cases of the montmorillonite type clays, due to their sharp drop in strength.
- (3) The casting chosen carried sufficient attraction for defects to make the above conclusions applicable to most commonly encountered work in automotive or agricultural implement production. Castings with heavy metal sections, weighing in excess of 100 lb. or most castings of 400 lb. or over, might bring out differences that could not be observed in this test.
- (4) The measured sand properties covered an unusually wide range, because of the radical difference in the types of clays used, yet defects commonly attributed to extremes of permeability, dry strength, or flowability were not consistently found at the limits encountered.
- (5) Molding practice, gating and pouring were responsible for more defects than those caused by deficiency in any clay property.

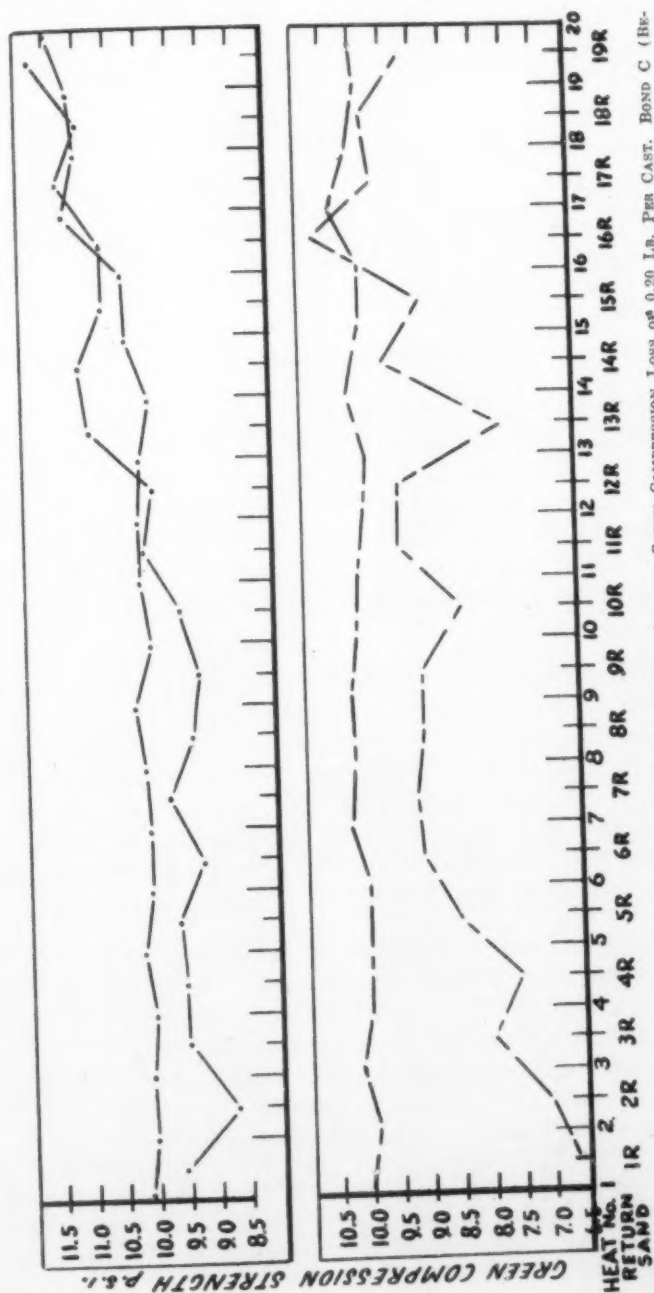


FIG. 2.—COMPARISON OF GREEN STRENGTH LOSS. BOND E (ABOVE) SHOWS AVERAGE GREEN COMPRESSION LOSS OF 0.20 LB. PER CAST. BOND C (BELOW) SHOWS AVERAGE GREEN COMPRESSION LOSS OF 1.29 LB. PER CAST.

Table 2

COMPARATIVE AMOUNTS OF BOND CLAY REQUIRED

	<i>Clay in Original Batch, lb.</i>	<i>Clay Additions For 20 Casts, lb.</i>
Illite (A)	20.0	8.75
Western Montmorillonite (B)	10.5	6.00
Southern Montmorillonite (C)	9.0	16.25
Kaolinite (E)	30.0	7.5

SAND PROPERTIES

Durability or Green Strength Losses

50. The great importance of durability in foundry sands or clays can be illustrated in Fig. 2. These two sands were chosen as they represent the high and low of the materials investigated. In the case of Sand "C," there was an average green compression strength loss of 1.29 lb. per sq. in. per cast, whereas sand "E" shows an average green compression strength loss of only 0.2 lb. per sq. in. per cast.

51. Table 2 gives the comparative amounts of bond used to obtain the original 10 lb. per sq. in. green compression strength and to maintain this strength throughout the 20 casts. A review of these figures will show how misleading it can be to evaluate a clay economically on the initial bonding power alone. For instance, again considering sands "C" and "E," it required over 3 times as much bond "E" as bond "C" to obtain the initial strength, but less than one-half as much to maintain this strength in use.

52. Sand to metal ratio in foundry practice will vary from 1 to 1 (carwheels, brake shoes, etc.) to as high as 10 or more to 1 (plate work, hollow ware, etc.) As previously mentioned, however, the 4 to 1 sand to metal ratio was chosen in this test as it was felt it represented a good average figure. Therefore, the figures on amounts of bond used indicate a durability or reserve strength factor for a 4 to 1 sand to metal ratio throughout 20 casts.

53. With this in mind, Fig. 3 was charted showing the comparison of the amount of bond added to maintain the strength to the total amount of bond used. For instance, in the case of the illite clay A

$$\text{Reserve Strength Factor} = \frac{\text{Original amount of bond added} + \text{Amt. of bond added to maintain strength}}{\text{Amt. of bond added to maintain strength}}$$

$$\text{Reserve Strength Factor} = \frac{20 \text{ lb. plus } 8.75 \text{ lb.}}{8.75 \text{ lb.}}$$

$$\text{Reserve Strength Factor} = 3.3$$

Therefore, if all of the bonds possessed equal reserve strength, using the illite clay as a basis (or a reserve strength factor of 3.3) the additions shown in Table 3 would have been necessary in maintaining the strength:

Table 3

AMOUNT OF CLAY REQUIRED TO MAINTAIN STRENGTH BASED ON
ILLITE CLAY

Type Clay	Lb.
Illite (A)	8.75
Western Montmorillonite (B)	4.56
Southern Montmorillonite (C)	3.91
Kaolinite (E)	13.05

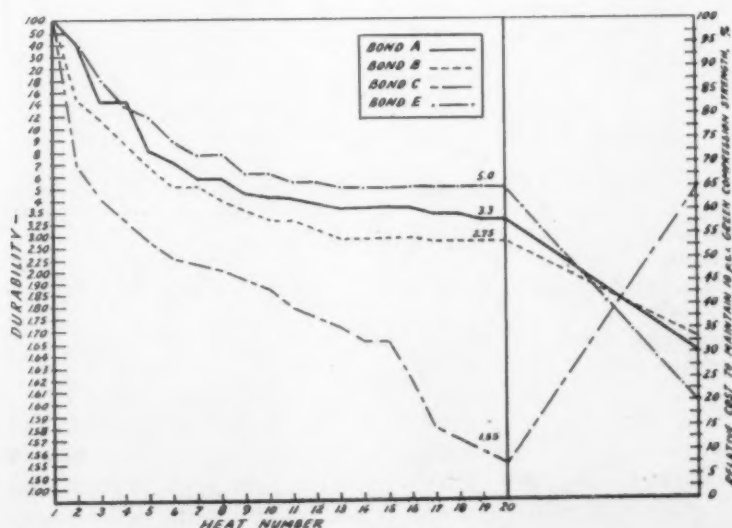


FIG. 3.—COMPARISON OF THE AMOUNT OF BOND ADDED TO MAINTAIN THE STRENGTH TO THE TOTAL AMOUNT USED. RIGHT-HAND CHART ILLUSTRATES THE COST DIFFERENTIAL ON RESERVE STRENGTH, EXPRESSED IN PERCENTAGES.

54. This was not true, however, and Table 4 shows the difference reflected by durability:

Table 4

COMPARISON DURABILITY FACTORS

	<i>Amount of Clay Necessary with a 3.3 Reserve Strength Factor, lb.</i>	<i>Amount of Clay Actually Required, lb.</i>	<i>Percentage Difference</i>
Illite (A)	8.75	8.75	same
Western Montmorillonite (B)	4.56	6.00	+ 31.6
Southern Montmorillonite (C)	3.91	16.25	+ 315
Kaolinite (E)	13.05	7.5	— 42.5

55. The right-hand chart in Fig. 3 illustrates the cost differential on reserve strength, expressed in percentages, and based on the following formula:

$$\text{Reserve Strength Cost} = \frac{\text{Cost of bond added to maintain strength}}{\text{Cost of bond added to obtain original strength} + \text{Cost of bond added to maintain strength}}$$

These comparisons are shown in Table 5.

Table 5

RESERVE STRENGTH FACTORS FOR VARIOUS TYPE CLAYS

	<i>Total Amount Used, lb.</i>	<i>Amount Required to Maintain Strength, lb.</i>	<i>Reserve Strength Factor</i>	<i>Reserve Strength Cost, per cent</i>
Illite (A)	28.75	8.75	3.30	30
Western Montmorillonite (B)	16.50	6.00	2.75	36
Southern Montmorillonite (C)	25.25	16.25	1.55	64
Kaolinite (E)	37.50	7.50	5.00	20

56. Fig. 4 is more indicative of what would result in the maintenance of heap or unit strengths. This chart gives the relationship between the amount of bond required for the initial strength and the amount of bond required to maintain this strength. The prime requirement in heaps or units is maintaining the strength and would compare with the reserve strength factors in Fig. 4 which are expressed in Table 6.

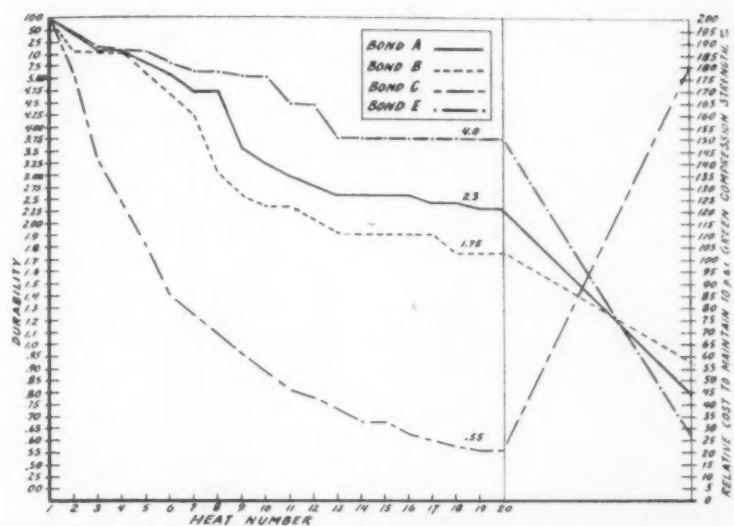


FIG. 4—RELATIONSHIP BETWEEN THE AMOUNT OF BOND REQUIRED FOR THE ORIGINAL STRENGTH AND THE AMOUNT OF BOND REQUIRED TO MAINTAIN THIS STRENGTH. RIGHT-HAND CHART SHOWS RELATIVE COST TO MAINTAIN STRENGTH, EXPRESSED IN PERCENTAGES.

57. The figures in Table 6 show that for every 100 lb. of bond necessary to obtain an initial heap or unit strength, it would require the amounts shown in Table 7 to maintain this strength.

Table 6

RESERVE STRENGTH FACTORS BASED ON AMOUNT REQUIRED TO MAINTAIN STRENGTH AFTER INITIAL ADDITION OF 100 LB.

BOND MATERIAL

	Amount in Original Batch	Amount Required to Maintain Strength	Reserve Strength Factor	Reserve Strength Cost, per cent
Illite (A)	20.00 lb.	8.75 lb.	2.3	44
Western Mont- morillonite (B)	10.50 lb.	6.00 lb.	1.75	57
Southern Mont- morillonite (C)	9.00 lb.	16.25 lb.	0.55	180
Kaolinite (E)	30.00 lb.	7.5 lb.	4.00	25

58. The figures in Table 7 show that while the montmorillonites have high initial green strength they do not possess the high degree of durability or reserve strength of illite or kaolinite.

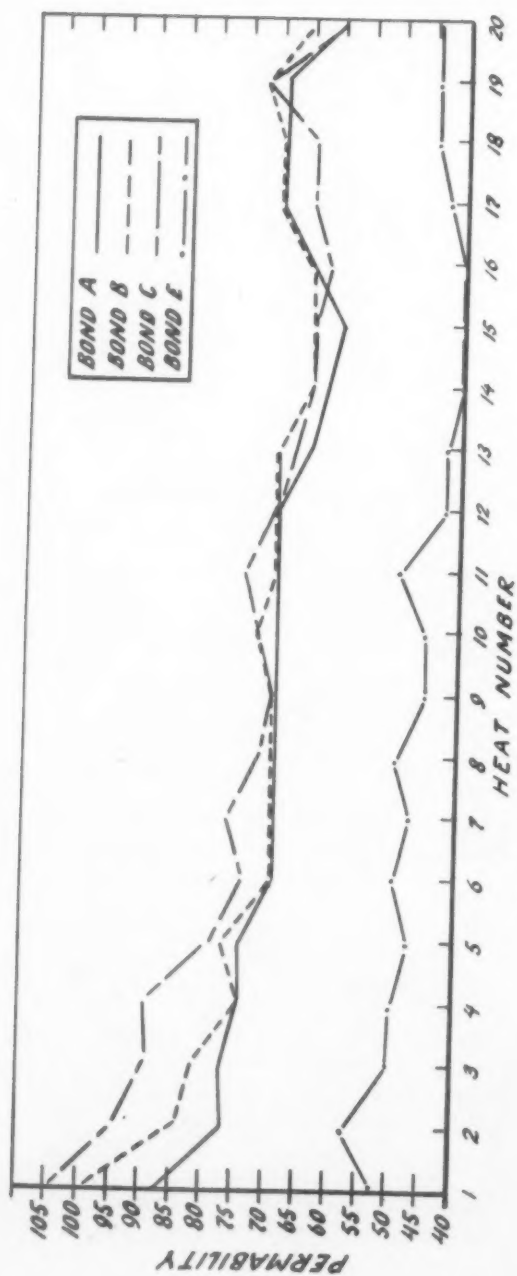


FIG. 5—COMPARISON OF PERMEABILITY THROUGH 20 CASTS.

Table 7

AMOUNTS REQUIRED TO MAINTAIN STRENGTH BASED ON 100 LB.
INITIAL BOND ADDITIONS

	<i>Lb.</i>
Illite (A)	43.5
Western Montmorillonite (B)	57.1
Southern Montmorillonite (C)	180
Kaolinite (E)	25

Permeability

59. Permeability curves are charted in Fig. 5. It will be noted that illite (A) and the montmorillonites (B and C) can be identified in the high permeability range and kaolinite (E) in a low permeability range. Illite and the montmorillonites are within 17 points of each other at the beginning of the test; 5 points after the 5th cast; 3 points after the 10th cast; 5 points after the 15th, and 5 points at the 20th cast.

60. In the case of kaolinite (E), the permeability was 52 at the start of the test or approximately 40 points lower than the average of illite or the montmorillonites. However, after the 7th cast this difference has been lowered to an average of 20 points. The percentage drop in permeability is shown in Table 8.

Table 8

VARIOUS PERMEABILITIES WITH DIFFERENT TYPE BONDS

	<i>Permeability at Beginning of Test</i>	<i>Permeability after 20 Casts</i>	<i>Difference</i>	<i>Percentage Difference</i>
Illite (A)	87	60	27	31
Western Mont- morillonite (B)	100	65	35	35
Southern Mont- morillonite (C)	105	60	45	43
Kaolinite (E)	52	45	7	14

61. There are two possible explanations in the levelling of permeabilities as the test progressed: (1) The addition of sea coal, and (2) the amounts of bond added to maintain strength. In the first instance the test results shown in Table 9 bear out this point. In the second explanation, it will be noted from Table 2, that the amounts added to maintain strength were in no way relative to the

initial amounts required, and would affect the permeabilities accordingly.

Table 9

EFFECT OF VARIOUS TYPE BONDING MATERIALS ON PERMEABILITIES
WITH UNIFORM ADDITIONS OF SEA COAL

	<i>Permeability in Original Mix with 6% Sea Coal</i>	<i>Permeability in Test Mixture without Sea Coal</i>	<i>Difference, Points</i>
Illite (A)	87	105	18
Western Mont- morillonite (B)	100	135	35
Southern Mont- morillonite (C)	105	150	45
Kaolinite (E)	52	65	13

62. Many castings require a sand of high permeability, and in some cases, it is expensive to accommodate this requirement through bond alone. A review of Table 8 might suggest an investigation of changes in base sand or sea coal screen analysis to fulfill higher permeability requirements.

63. For instance, to obtain the same permeability with kaolinite as in the original range of either illite or the montmorillonites, the change in screen analysis of the sand as shown in Table 10 could be used.

Table 10

COMPARISON OF BASE SANDS TO PRODUCE THE SAME PERMEABILITY
IN MIXTURES USING DIFFERENT CLASSES OF CLAYS

	<i>Base Sand One Used in Test</i>	<i>Base Sand Two for Higher Perm.</i>
On 30	0.2	0.2
40	0.2	10.8
50	12.5	35.2
70	37.6	25.1
100	37.8	20.9
140	9.5	6.4
200	1.8	1.2
270	0.4	0.1
Pan	0.2	0.1
A.F.A. Fineness No.	63	53

64. Through the use of sand two, it was possible to increase the permeability 46 points, or from 52 for sand one to 98 with sand

two. Both sands were bonded with the same percentage of clay, to a 10 lb. green strength and contained 6 percent sea coal. The permeability of 98 compares very favorably with those of sands A, B or C, at the first heat and Table 8 will indicate that the permeability in use should not be lowered to any greater degree.

Table 11

PERMEABILITIES OBTAINABLE BY ADJUSTMENT OF GRAIN SIZE AND DISTRIBUTION

<i>Mesh Size</i>												
On 20	33											
30		33										33
40			33							33	33	33
50				33					33	33	33	33
70	33	33	33	33	100			33	33	33		
100				33			33	33	33			
140			33			33	33	33				
200		33				33	33					
270	33					33						
Pan												
Base Per-												
meability	30	55	85	135	200	20	35	70	135	270	450	

65. Table 11, made from curves used in a paper by H. W. Dietert³, gives rather interesting changes that can be obtained in permeabilities with proper adjustment in grain size and distribution.

Table 12

SCREEN ANALYSIS OF TWO SEA COALS

	<i>No. 3</i> <i>Sea Coal</i>	<i>No. 3C</i> <i>Sea Coal (fines removed)</i>
On 20	0.5	0.3
30	3.0	3.1
40	7.0	8.0
50	10.5	14.0
70	10.8	15.7
100	14.2	21.2
140	11.9	16.9
200	9.1	9.1
270	4.4	2.7
Pan	28.6	9.0

³ Dietert, H. W., "Grain Structure Control Insures Mold Permeability Control," TRANSACTIONS, American Foundrymen's Association, vol. 41, pp. 175-192 (1933).

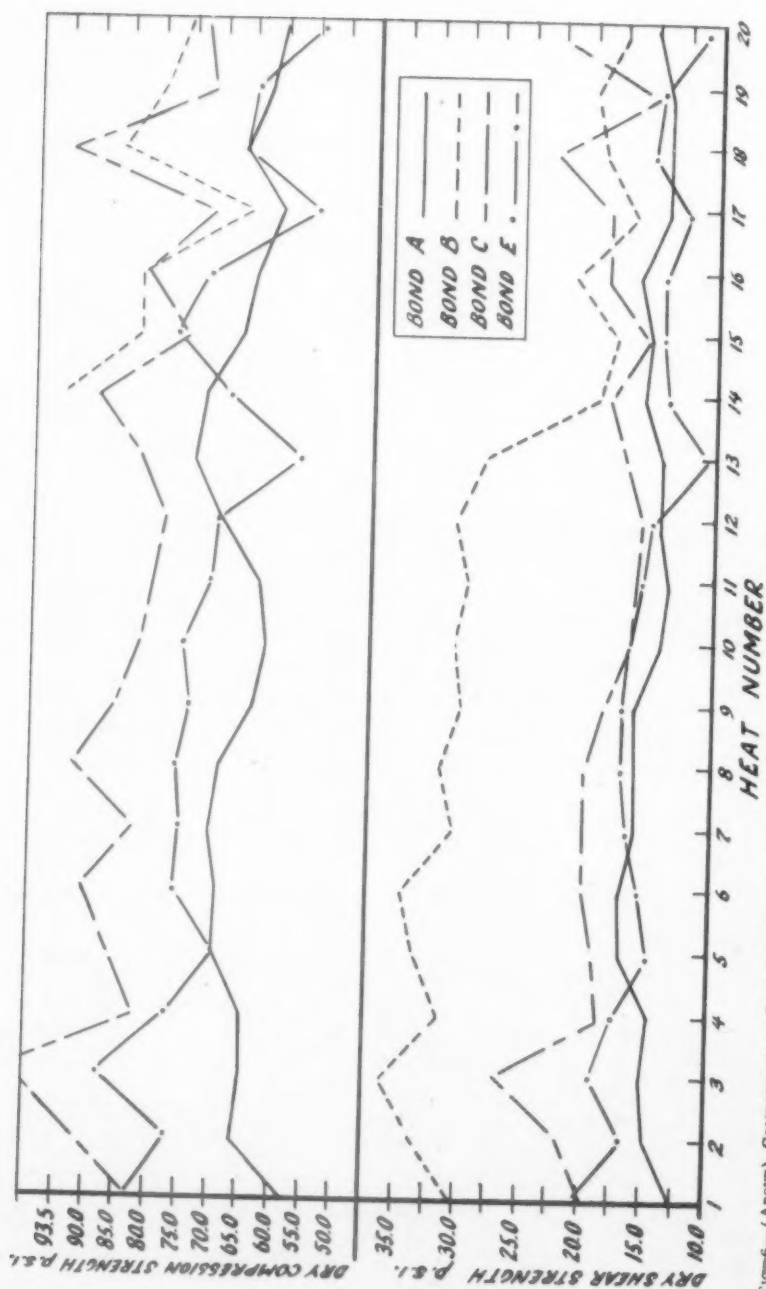


FIG. 6. (ABOVE) COMPARISON OF DRY COMPRESSION STRENGTH THROUGH 20 CASTS. BOND B ABOVE CAPACITY OF MACHINE UNTIL 14TH CAST. (BELOW) COMPARISON OF DRY SHEAR STRENGTH THROUGH 20 CASTS.

66. Important adjustments can be made in permeabilities also through selection and control of sea coal screen size, as shown in Table 12. An addition of 6 per cent of each of these sea coals to the same base sand, and bonded with the same amount and type of clay, shows that sea coal 3C will give a 46 per cent increase in permeability, or 90 as compared with 48 for the sea coal 3.

Dry Strength

67. Dry strength properties are charted in Fig. 6. Western montmorillonite (B) shows highest dry strength, with southern montmorillonite (C) next, followed by kaolinite (E) and illite (A), respectively. Illite (A) possesses the most uniform dry strength. Western montmorillonite (B) showed a sharp drop in dry strength after the 13th cast. This may be caused at least in part by changes in clay particle size, but the complete answer should provide an interesting problem for further study. Southern montmorillonite (C) is known to possess low dry strength in straight clay-sand mixtures but the presence of sea coal alters this property. Table 13 gives a comparison of dry strength properties with and without sea coal.

Table 13

COMPARISON OF STRENGTH PROPERTIES WITH AND WITHOUT SEA COAL

	<i>Dry Strength Without Sea Coal, lb.</i>		<i>Dry Strength With 6 per cent Sea Coal, lb.</i>		<i>Per cent Increase</i>	
	<i>Compression</i>	<i>Shear</i>	<i>Compression</i>	<i>Shear</i>	<i>Compression</i>	<i>Shear</i>
Illite (A)	54.0	12.0	57.7	12.5	6.8	4.2
West. Mont. (B)	*	25.2	*	30.0	*	19.2
South. Mont. (C)	50.2	11.3	81.5	19.5	62.3	72.6
Kaolinite (E)	61.7	13.2	83.0	20.5	34.5	55.3

68. After reviewing the great levelling effect of use on dry strength properties, one might explain losses due to cuts or washes on certain types of castings which require high dry strength. In fact, it may be advisable to consider the use of an auxiliary binder of the cereal or resin type to insure maintenance of higher dry strength properties where they are required. This auxiliary binder would only be necessary to increase the dry strength of facing sands. After the mold was poured it would burn out and not cause difficulty from "hot cracks" or lumpy sand at the shake-out. The

* Dry compression strengths above capacity of standard machine.

test data of Table 14 shows what increases can be made in dry strengths through the addition of a cereal binder or a high dry strength clay bond, to a low dry strength clay.

Table 14

VARIATIONS IN DRY STRENGTH OBTAINABLE WITH AUXILIARY BINDERS

<i>Illite (A)</i> <i>Original Mix</i> <i>Dry Shear,</i> <i>lb.</i>	<i>Original Mix-Illite (A)</i> <i>plus 1.0% Cereal</i> <i>Dry Shear, lb.</i>	<i>Per cent</i> <i>Increase</i>	<i>6.75% Illite*</i> <i>1.25% Western Montmorillonite*</i> <i>Dry Shear, lb.</i>	<i>Per cent</i> <i>Increase</i>
12.7	25.3	100	26.3	108
<i>Kaolinite (E)</i> <i>Original Mix</i> <i>Dry Shear, lb.</i>	<i>Original Mix-Kaolinite</i> <i>plus 0.5 per cent Cereal</i> <i>Dry Shear, lb.</i>	<i>Per cent</i> <i>Increase</i>	<i>10.0% Kaolinite*</i> <i>1.25% West. Mont.*</i> <i>Dry Shear, lb.</i>	<i>Per cent</i> <i>Increase</i>
20.5	27.7	35	27.0	31.7

69. The figures obtained from the shake-out practice followed in this test are quite interesting and bear out the fact, which is generally recognized, that the amount of sand adhering to the casting after shake-out, or that which is lost from units in the form of "tailings"⁴ is directly related to the dry strength. These figures are shown in Table 15.

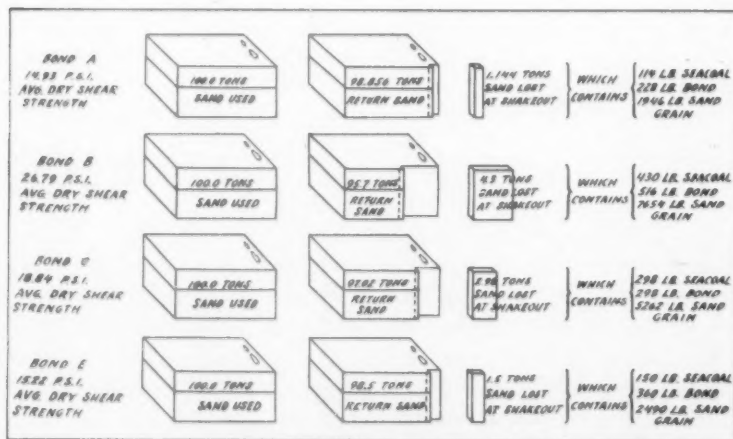


FIG. 7—SAND LOSSES IN RELATION TO DRY SHEAR STRENGTH.

* Percentages required to obtain 10 lb. green compression strength.

⁴ Lumps of molding sand carried out with core butts in screenings.

Table 15

EFFECT OF DRY STRENGTH ON SAND ADHERING TO CASTINGS

	<i>Illite</i> <i>A</i>	<i>Western</i> <i>Montmorillonite</i> <i>B</i>	<i>Southern</i> <i>Montmorillonite</i> <i>C</i>	<i>Kao-</i> <i>linite</i> <i>E</i>
Average dry shear strength, lb.	14.93	26.79	18.84	15.22
Average weight of sand in mold, lb.	172.2	169.86	172.06	177.82
Average weight of adhering sand, lb.	1.97	7.41	5.13	2.66
Percentage of adhering sand	1.14	4.3	2.98	1.5

70. It should be kept in mind that every pound of sand that is lost at the shake-out either carried out on the castings or through "tailings," contains good sand grain sea coal and bond. Fig. 7 will illustrate rather clearly what this would amount to from the economical standpoint, on the basis of the turnover of 100 tons of sand, which would represent only 5-10 floors in a non-mechanized foundry or about 1 hour's operation in most production units. With Illite (A), which had an average dry shear strength of 14.93 lb. from a 100 ton turnover, there would be 98.856 tons of return sand or 1.144 tons lost at the shake-out which sand contains 114 lb. seacoal, 228 lb. bond and 1,946 lb. of sand grain.

71. No flask bars were necessary in making the molds, but it was felt that the different dry strength characteristics would have presented some further interesting data on shake-out time.

Flowability

72. Flowability properties are charted in Fig. 8. There is little difference in the flowability characteristics. This fact can be explained by the very close tempering practice followed.

Deformation

73. Deformation properties are charted in Fig. 9. This property is quite uniform for the individual bonds and again this can be attributed to the close tempering practice followed.

Moisture

74. Fig. No. 10 shows the moisture content curve for the different sands, as used. The sands were tempered to best workable moisture.

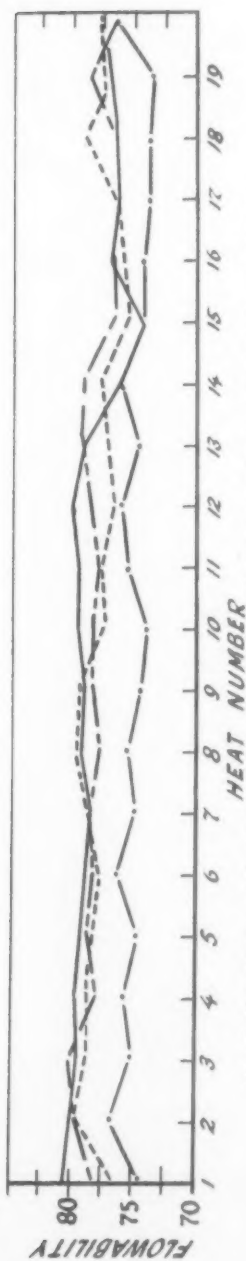


FIG. 8—COMPARISON OF AVERAGE FLOWABILITY PROPERTIES THROUGH 20 CASTS. (SEE FIG. 3 FOR LEGEND.)

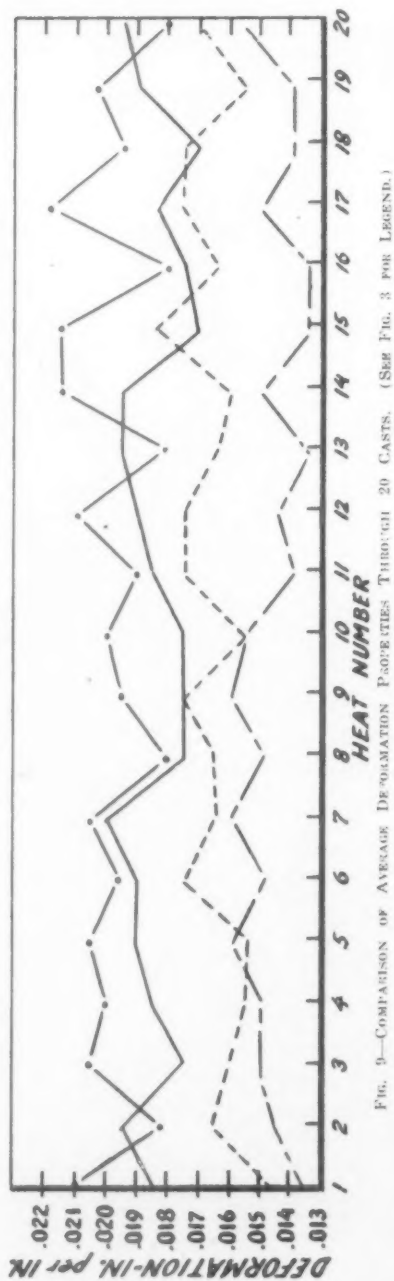


FIG. 9—COMPARISON OF AVERAGE DEFORMATION PROPERTIES THROUGH 20 CASTS. (SEE FIG. 3 FOR LEGEND.)

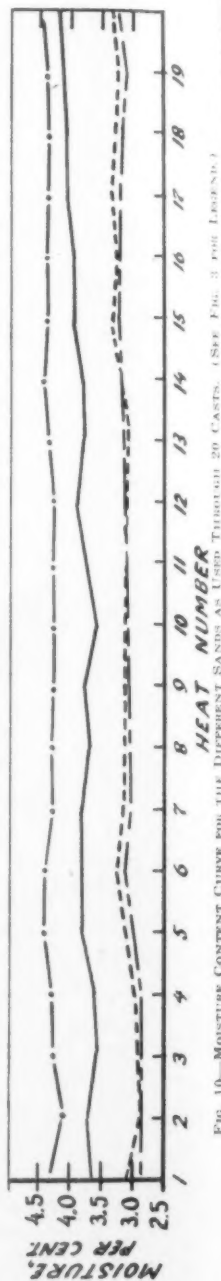


FIG. 10—MOISTURE CONTENT CURVE FOR THE DIFFERENT SANDS AS USED THROUGH 20 CASTS. (SEE FIG. 3 FOR LEGEND.)

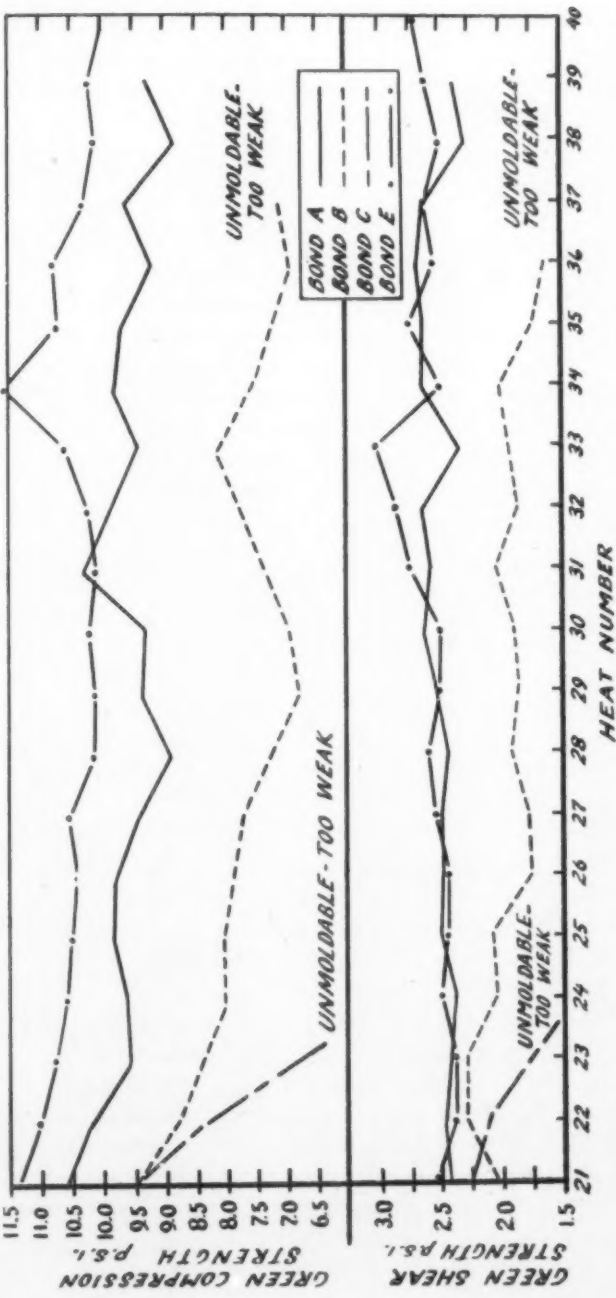


FIG. 11—COMPARISON OF GREEN STRENGTH CHANGE IN BREAKDOWN TEST. SAND C BECAME UNMOLDABLE AFTER 22ND CAST. SAND B BECAME UNMOLDABLE AFTER 36TH CAST.

BREAKDOWN TEST

75. At the completion of the maintenance test, all sands were subjected to a breakdown test. This series of tests was completed in the same manner as the maintenance test, except that no bond, sand or sea coal was added. The test proceeded until the sand was either unmoldable or until there was insufficient sand to make a mold.

76. Green strength changes in the breakdown test are charged in Fig. 11. Sand "C" became unmoldable due to loss of green strength after the 22nd cast (2nd breakdown cast). Sand "B" became unmoldable for the same reason after the 36th cast (16th breakdown cast). Sands A and E were discontinued at the end of heats 39 and 40, respectively, due to lack of sand for a satisfactory mold, although the sands were still moldable and possessed high comparative green strengths. The manner in which illite (A) and kaolinite (E) maintained strength throughout this test can again be attributed to their high durability.

77. Fig. 12 gives a comparison of the other sand properties during the breakdown test. Dry strengths, flowability and deformation properties would be expected to vary during this test due to differences in green strengths.

78. Illite (A) continued to maintain a uniform dry strength, in relation to the green strength. The only exception was the change from the 27th to 28th heat wherein the green compression strength was lowered from 9.45 to 8.9 lb. without a comparative lowering of dry strength.

79. The relationship between green and dry strengths on western montmorillonite was very erratic. The dry strengths show a continuous downward trend after the 30th cast, in spite of the slight increase in green strength between the 30th and 33rd cast, after which there is a sharp loss in green strength also.

80. The one rather unusual point on kaolinite is at the 34th cast where the green strength increases to 11.5 lb. and the dry strength drops to almost its low point for this test.

81. It would be almost impossible to draw definite conclusions on other than green strength properties or durability in this test but certainly there are many indications that considerable changes in sand properties come about through use. Many lines of thought are suggested as to why these changes take place among which are the following:

1. Changes in clay particle size.

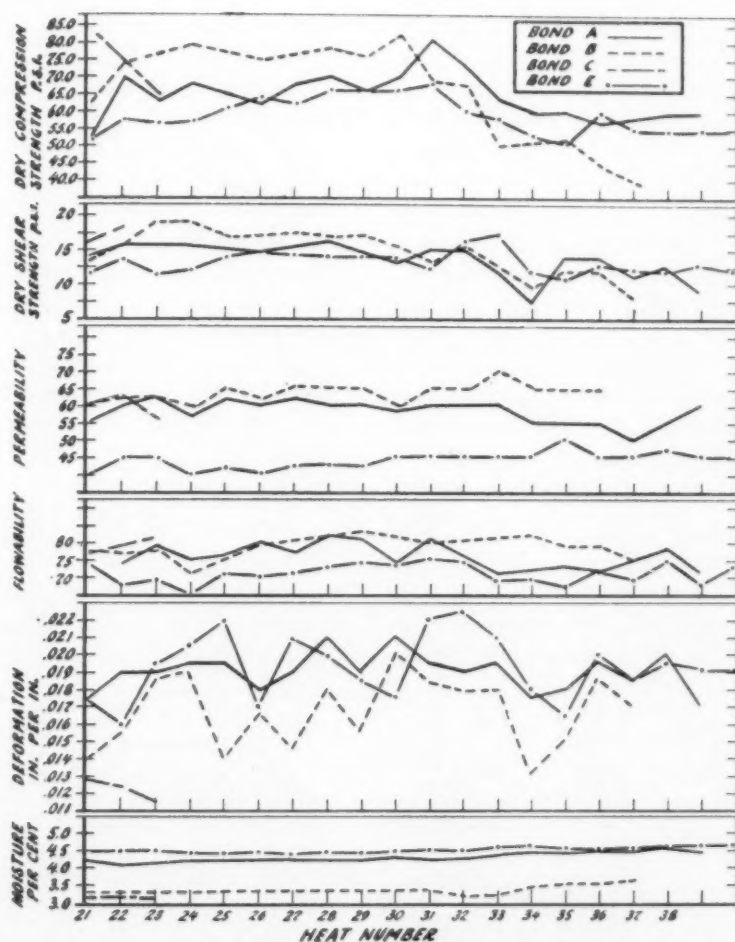


FIG. 12—COMPARISON OF MOISTURE, DEFORMATION, FLOWABILITY, PERMEABILITY, DRY SHEAR STRENGTH AND DRY COMPRESSION STRENGTH PROPERTIES DURING BREAKDOWN TEST.

2. Changes in sand grain structure.
3. Changes in sea coal.

MULLING TEST

82. The phenomena of strength increases for illite (A) and kaolinite (E) during the later stages of the maintenance test and also at intervals during the breakdown test were also thought to be from the increase in per cent potential strength from cumulative effects of mulling. Mulling tests were therefore completed, wherein all new batches of the original mixtures were prepared and com-

plete test results taken at one minute intervals and proceeding until the green strength levelled off.

83. It will be noted from the green strength charts, Fig. 13, that the belief as regards increases in green strength due to mulling is not entirely true, as illite and kaolinite reach as high a percentage of potential strength as the montmorillonites in the standard mulling procedure of 2 min. dry and 5 min. wet. It is due, entirely, to the higher durability of illite and kaolinite.

84. The dry strength curves, Fig. 14, are interesting, particularly as regards illite (A), which reached its maximum dry strength after a total of 4 min. mulling time and maintained this strength for the balance of the 15 min.

85. It also will be noted that, in spite of the increases in green strengths, all of the bonds appeared to level off in dry strengths after a total of 8 min. mulling.

CONCLUSIONS

Bonding Costs

86. The commonly used method of evaluating different type clays by merely comparing costs of material required to bond a sharp sand to a certain strength is misleading. In green sand production, with an average 4:1 sand-metal ratio, a comparison of clay

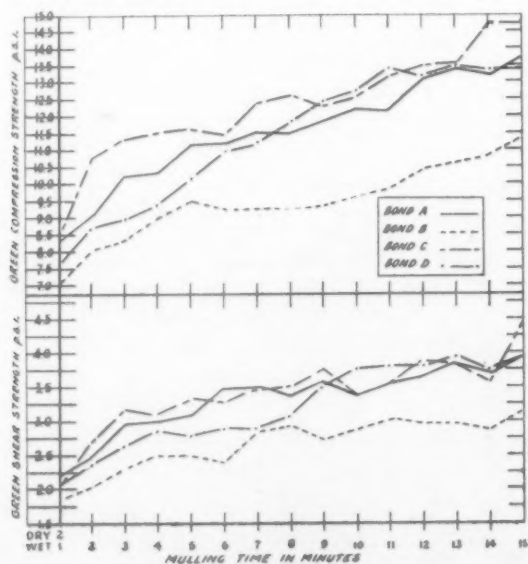


FIG. 13—COMPARISON OF GREEN STRENGTH DURING MULLING TEST. COMPLETE TEST RESULTS TAKEN AT ONE MIN. INTERVALS UNTIL GREEN STRENGTH LEVELLED OFF.

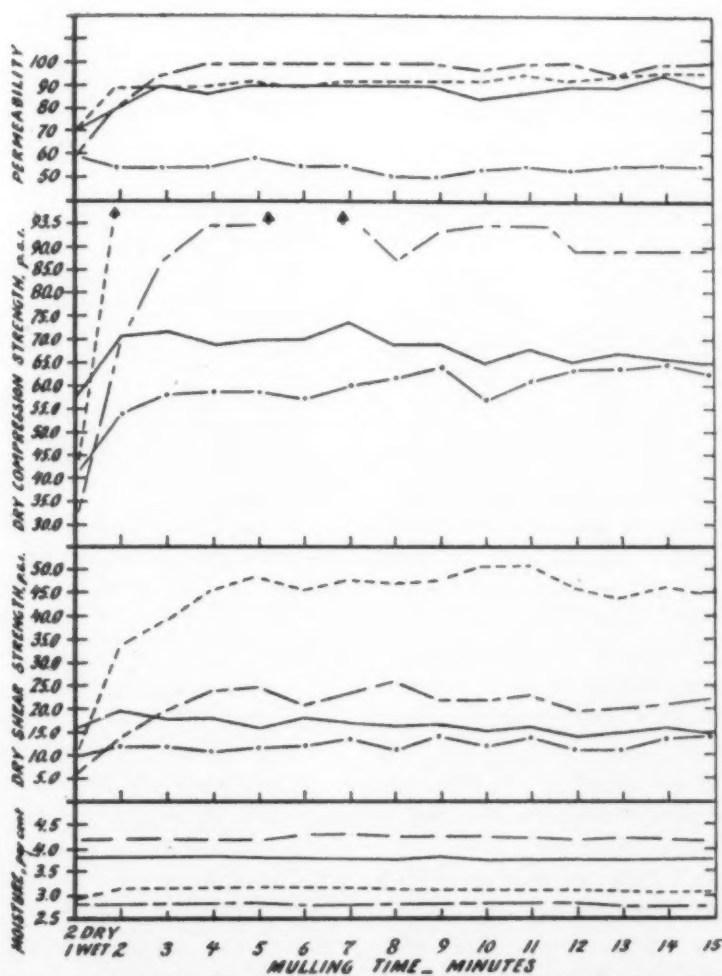


FIG. 14—COMPARISON OF MOISTURE, DRY SHEAR STRENGTH, PERMEABILITY AND DRY COMPRESSION STRENGTH PROPERTIES DURING MULLING TEST. (SEE FIG. 3 FOR LEGEND.)

costs may be made by the use of the reserve strength cost factor. Consideration of durability must be used in any accurate clay evaluation.

87. Costs of maintaining strength in sand handling systems or heaps, where illite or kaolinite type bonds are used, could frequently be reduced by taking advantage of the reserve strength imparted to the sand by these types of bonds and occasionally reducing or eliminating bond additions. It is found that the strength

does not drop off sharply as is the case with montmorillonite bonded sands.

88. Considerable savings in clay, sea coal and new sand grain additions can be made with an illite bonded sand. This is clearly proved by the average weight of sand adhering to the castings, which is directly related to the average dry strength.

89. The amount of mulling given the sands can be an important cost factor. The mulling period used in this investigation is longer than that most commonly used in practice, yet only from 78 to 80 per cent of the total potential maximum strength was obtained on the initial batch.

Sand Characteristics

90. *Green Strength.* The montmorillonites are initially stronger, followed by illite, with the kaolinite last. This relative position on initial unused sands is the same with or without sea coal. The loss of green strength with use, however, is least with the kaolinite and illite and highest with the montmorillonites, the southern variety of which loses about six times as much green strength with each use as does the kaolinite.

91. *Dry Strength.* This property undergoes considerable change during the use of the sands bonded by the montmorillonites. The illite showed the least variation in this property. The initial sands, unused, but containing sea coal, are relatively different than unused sands without sea coal. Comparisons of bonds on the basis of the property should take into consideration the effects of added sea coal and re-use.

92. *Permeability.* The montmorillonites and illite are substantially the same in their effects on permeability, all being higher than the kaolinite. The margin between the high permeability types and the kaolinite, however, is reduced by about 75 per cent with re-use. This suggests that premium purchase of high permeability type bond may be more costly than the use of a fire clay bond with adjustment in sand grain size and distribution, or a "fines removed" sea coal.

93. *Flowability.* Illite bonded sands have the highest flowability and kaolinite the lowest. None are sharply affected by re-use.

94. *Deformation.* The kaolinite shows the highest deformation and the montmorillonites lowest. Illite shows the least change in this property with re-use.

DISCUSSION

Presiding: L. B. KNIGHT, Jr., National Engineering Co., Chicago, Ill.

Co-Chairman: F. L. WEAVER, Great Lakes Foundry Sand Co., Detroit, Mich.

N. J. DUNBECK¹ (*written discussion*): In view of the complete nature of the tables presented, it is regrettable that actual additions of clay after each heat were not given. Fig. 1 indicates that the kaolinite bonded return sand had higher than initial strength on most of the last seven heats. Presumably, no additional clay was required. Sand conditions seem to have changed during the second ten heats as compared to the first ten heats which might affect the conclusions reached.

The authors reach firm conclusions as to the relative durability of kaolinite, montmorillonite and illite. These conclusions are obviously too far reaching since there are good and bad kaolinites and good and bad clays of the other types. In our experimental work we have found as great a difference in durability between a good and bad kaolinite as is here indicated between dissimilar types of clays. The authors have shown the durability of the particular samples of clay tested, but these results cannot be accepted as representative of all other clays of the same types.

It is shown that western montmorillonite has double the durability of southern montmorillonite, and it is inferred that this condition would prevail in regular foundry practice. If true, the southern product would be so costly that it would have no commercial application. As a large number of foundries use the southern material, the conditions of the test are apparently at fault as a basis of comparison for the commercial application of the material.

In the breakdown test, the kaolinite bonded sand decreased in strength only from 11.4 to 10 lb. in twenty pourings with no additions of fresh bond. Presumably, such a sand could have been used for twenty more heats and still have adequate strength. The inference is that a similar sand in a foundry heap could run twenty to forty days with no bond additions. This seems extremely improbable.

In the mulling test, it is pointed out that illite and kaolinite reach as high a percentage of their potential strength in seven minutes mulling as do the montmorillonites. This may be true, but it is equally true that few foundries have sufficient mulling capacity to mull for seven minutes and that a total of four minutes mulling is probably average or better than average. It is shown in the paper that kaolinite developed only 88.2 per cent of its seven minutes strength in 4 minutes mulling, while southern montmorillonite developed 99.1 per cent.

Under the heading "Sand Specifications", it is stated that all sands were bonded to 10 lb. green compression strength. In an otherwise complete paper, the tables of actual strengths were omitted and curves showing the strengths of only two clays are presented in Fig. 2. This figure gives an initial strength of 10 lb. for southern montmorillonite

¹ Eastern Clay Products, Inc., Eifort, O.

and 10.1 lb. for kaolinite. In the mulling test, however, in which "all new batches of the original mixtures were prepared", the green strengths after the same seven minutes mulling as in the durability tests were:

Clay A—Illite	11.2
Clay B—Western Montmorillonite	9.2
Clay C—Southern Montmorillonite	11.5
Clay E—Kaolinite	10.9

If the tests are not reproducible, there is some doubt as to their value. If the western montmorillonite was started at a strength approximately 18 per cent lower than the illite, this might be expected to affect the results obtained.

Despite an initial strength which is three times as great as kaolinite, southern montmorillonite is shown to require additions in daily use which are twice as great as kaolinite. Based on the actual conversion of a great many foundries from kaolinite to southern montmorillonite, we know that is not only untrue but that it does not remotely correspond to actual facts in practice.

H. RIES²: This is a very interesting paper which must be read before it can be discussed with any degree of detail. How were those dry strengths determined? Were the specimens proved before they were tested?

MR. OVERSTREET: The specimens were allowed to cool on the bench and carefully observed for test when they reached room temperature. They were not cooled in a desiccator which may have been a discrepancy, although tests in our laboratory have not shown great differences, if the samples are tested as soon as they reach room temperature. Also, paragraph 189, *Testing and Grading Foundry Sands and Clays*, does not specify that the specimen must be cooled in a desiccator. We know, however, that if the samples are permitted to stand for any length of time, after reaching room temperature, the dry strengths will be lower. The only possible discrepancy which could occur in this instance would be if the different bonds would be affected differently, which we do not believe would be the case.

It might be mentioned, also, that in a test of this nature, where simulation of foundry practice was of prime importance possibly testing as soon as the specimen was removed from the oven would have been more comparative. Cracked castings, from too high a dry strength, are caused when the sand is still hot. Also, difficulties at shake-out usually always occur when the sand is still hot as it does not have time to cool.

DR. RIES: Were they the standard test specimens?

MR. OVERSTREET: Regular test specimens, 2-in. high and 2-in. wide.

DR. RIES: We have a couple of desiccators at Cornell of large diameter and height and a large number of specimens can be piled in them. The results will be different whether the specimen is cooled in the air or in the desiccator. The strength will probably be lower when cooled in the air than when cooled in the desiccator.

² Technical Director, A.F.A. Foundry Sand Research Committee, Ithaca, N. Y.

H. H. FAIRFIELD³: I want to bring up the point of temperature again. In industry, the temperatures of the molds vary. Sometimes they are so hot that you cannot put your hand on them. Now this investigation was very thorough and I commend the authors on it, but I would like to get their comments on the effect of temperature on these results. I think if the molds were hot, they would get different results with these clays than if the molds were at room temperature.

MR. NICHOLS: We have not considered the point you make, that is, solely from the standpoint of temperature. It is a matter of the sand to metal ratio. We qualify our statement, and I think a durability test must be applied by whatever sand to metal ratio is adopted. That determines the length of time the casting is in the mold, the temperature of the mold, and the pouring temperature. We believe that the four-to-one sand-to-metal ratio used is probably representative of a wider range of general castings production than almost any other ratio.

MR. FAIRFIELD: I was not questioning the ratio of sand to iron. I was bringing up the fact that hot sand from the shake-out returns to the mixer, is mixed, then goes to the production line, and the mold is actually hot. The iron goes in over that sand, and the result may be different than if the sand is at room temperature.

MEMBER: Have you seen Mr. Fairfield's paper on *Statistical Methods as an Aid to Control Foundry Operations**? The work described in this paper was conducted in industries in St. Catharines, Ont., Canada, over a long period of time which, I think, is an excellent procedure. It does not take close control and detailed analysis, but it does take practice in one shop over a long period of time. It takes into consideration all the variables, the findings on the effect of sand temperature.

MEMBER: We have a very fine sand, and, when adding the synthetic bonds, the biggest problem we have is keeping little clay balls from forming in the sand. Have any observations been made that might give an indication of the cause?

MR. NICHOLS: We did not find it so. If there had been much of a tendency with any of the bonding materials, it would have shown up in the permeability characteristics. The sands from the previous day were not prepared until the following day and were fairly well dried out. They were mulled dry, with bond and sea coal additions for 2 minutes and then 3 minutes wet. A common cause for so-called clay balls or sea coal balls in foundry sand is improper mixing, wherein water is added either before or during the time the bond and sea coal are added to the mill. If the bond or sea coal is added to the mill in a "sprinkling" manner, where the return sand is damp, there is little, if any, possibility of "balling."

In addition to the above procedures, and considering the fact that you use a very fine sand, you should also use extremely finely pulverized clay.

W. A. O'BRIEN⁴: Has any information been secured, through these

³ Mines and Geology Branch, Canadian Dept. of Mines and Resources, Ottawa, Ont., Canada.

* See pp. 611-636.

⁴ Electric Auto-Lite Co., Fostoria, O.

tests or previous tests, as to the ability of the sands to be carried by air, such as the green sand blowing operation?

MR. OVERSTREET: One malleable foundry is blowing quite a large green sand core. It involved considerable experimental work on their part before they were able to do it. The mold weighs probably 15 lb. and is used in a double breakhead where the two breakheads are cast in a mold. One of the points determined by them was the necessity of having the right strength and moisture content with the sand just a little bit on the dry side. To overcome this, they added a small amount of fuel oil.

MR. O'BRIEN: It is quite contrary to my practice. At one time I used an Ohio clay as a bond, and I had to carry my sand dry. Eventually, I switched to this one particular type of bentonite and I have been able to increase the moisture and permeability, and still have better results.

H. WOMOCHEL⁵: It appears to me that we are neglecting the most important thing that can be learned from a study of this kind, at least so far as the discussion is concerned, and that is, which of these mold materials is going to produce the best castings? Foundries operate to produce good castings, and I think the authors should give some discussion of the results so far as they concern the ability of these various molds to produce good castings. We have not had an opportunity to read the paper, but it seems illogical to neglect the most important thing to be learned from a paper of this kind in the presentation.

Table 16

RESULTS OF FINENESS TEST

Mesh Size	Sand "A" per cent	Sand "B" per cent	Sand "C" per cent	Sand "E" per cent
On 12	tr.	tr.	tr.	0.1
20	0.4	0.2	0.2	0.7
30	0.8	0.2	0.3	0.8
40	2.3	0.6	0.7	2.0
50	9.5	8.2	9.0	7.6
70	29.8	32.8	34.0	26.2
100	31.8	33.8	31.8	31.4
140	7.6	8.8	8.8	9.2
200	2.0	2.4	2.6	2.4
270	0.6	1.0	1.2	1.2
Pan	1.0	1.0	1.4	1.6
Clay	14	11	10	16.8
Perm. at End of Test	60	65	60	45
Perm. at Start of Test	87	100	105	52

MR. NICHOLS: If you will refer to the paper, you will find a rather detailed study of the casting defects given from page 1266 to and includ-

⁵ Michigan State College, East Lansing, Mich.

ing page 1270. I would like to make an observation, namely, with few exceptions, we made good castings from practically all.

There were many other variables that seemed to influence what defects we obtained, much more than any of the bonds. That is our general conclusion from a study of all the castings made. Detailed studies of several of the castings from the tenth to the twentieth heats are given in the paper.

H. W. DIETERT⁶: In the fineness test at the end of the run on the sand grain, there was quite a drop in permeability. Was that due to the sand grain breaking up?

MR. NICHOLS: The results of the fineness test on the different sands are shown in Table 16.

These screen analyses suggest additions to the paragraphs on permeability. It will be noted that the fines (minus 140 mesh) in each sand at the conclusion are as follows:

	<i>Per cent</i>
Bond "A"	3.6
Bond "B"	4.4
Bond "C"	5.2
Bond "E"	5.2

It is often thought that the more bond necessary to obtain the required strengths, the greater the development of fines through dehydration of the bonds. The above figures might indicate that this is not entirely true. For instance:

	<i>Amt. Required To Obtain Original Strength lb.</i>	<i>Amt. Required To Maintain Strength lb.</i>	<i>Fines (-140 mesh) In Final Sand per cent</i>
Bond "A"	20	8.75	3.6%
Bond "B"	10.5	6.0	4.4%
Bond "C"	9	16.25	5.2%
Bond "E"	30	7.5	5.2%

Therefore, the development of fines in spite of amounts added for all bonds is quite similar or from 3.6 per cent to 5.2 per cent for 20 casts. But there might be the question of some fines being washed out as clay content in the sand washing, which suggests the following:

	<i>Clay Added to Orig- inal Batch per cent</i>	<i>Clay in Final Sands as Washed per cent</i>	<i>Differ- ence per cent</i>	<i>Fines in Final Sands per cent</i>	<i>Total Possible Fines per cent</i>
Bond "A"	10.0	14.0	4.0	3.6	7.6
Bond "B"	5.25	11.0	5.75	4.4	10.15
Bond "C"	4.5	10.0	5.5	5.2	10.7
Bond "E"	15.0	16.8	1.8	5.2	7.0

⁶ Harry W. Dietert Co., Detroit, Mich.

These figures can be offered as further proof that while the stronger montmorillonite bonds give higher initial permeability due to smaller initial additions they likewise will show greater decreases in permeability, as illustrated in Fig. 3 and Table 8.

The suggestion of using a slightly coarser base sand for either illite or kaolinite when higher permeabilities are required should be more desirable with this further assurance of less development of "fines."

MESSRS. NICHOLS, HINTZE AND OVERSTREET (*authors' closure*): In reply to Mr. Dunbeck, the actual additions of clay (lb.) after each heat during which clay was added are shown in Table 17.

Table 17
ADDITIONS OF BOND AFTER EACH HEAT IN LB.

Heat No.	Illite	West. Mont.	South. Mont.	Kaolin-ite	Heat No.	Illite	West. Mont.	South. Mont.	Kaolin-ite
1	0.5	0.75	1.5	0.75	11	0.5	0.5	0.5	—
2	1.0	0.25	1.25	1.0	12	0.5	0.5	0.75	0.75
3	—	—	1.0	0.5	13	—	—	1.0	—
4	1.0	0.75	1.25	0.5	14	—	—	—	—
5	0.75	0.75	1.5	1.0	15	—	—	1.0	—
6	1.0	—	1.0	1.0	16	0.5	—	0.75	—
7	—	1.0	1.0	—	17	—	0.5	0.5	—
8	1.5	0.5	1.0	1.0	18	0.5	—	0.25	—
9	0.5	0.5	0.75	—	19	—	—	0.25	—
10	0.5	—	1.0	1.0					

Total for 20 Heats

	Lb.
Illite	8.75
Western Mont.	6.00
Southern Mont.	16.25
Kaolinite	7.50

The presumption that no additional clay was required in the kaolinite bonded return sand, during the last seven heats, is correct.

As stated in our conclusions, this phenomenon, as well as that in the similar cases of illite and western montmorillonite, is interpreted as being due to relative durability. It should provide an interesting source of further study to determine the exact nature of this durability; for instance, the question of whether the reserve strength evidenced is due to a fundamental difference in the mineralogical structure of the different clay types or to the decrease in particle size by thermal treatment during use, as suggested by C. E. Schubert*. The clouding of X-ray pictures by the presence of sea coal renders this further investigation difficult, yet certain properties are so changed by the presence of sea coal that its omission is misleading when the results are adapted to actual foundry use.

In regard to the changes in sand conditions in the second ten heats,

* Schubert, C. E., "Correlation of the Physical and Chemical Properties of Clays with the Durability of Molding Sands," TRANSACTIONS, American Foundrymen's Association, vol. 45, pp. 661-690 (1937).

aside from the equalization of permeabilities for illite, western montmorillonite and southern montmorillonite, the only great change was in the dry strength of the western montmorillonite bonded sand which shows a sharp decrease after the 13th cast.

Mr. Dunbeck's point in regard to the choice of materials was carefully considered by us in the selection of the bonds used. Our selection was based entirely on the extent to which the different bonds tested are used in the industry. We made no effort to investigate any clay far enough off type to be considered "bad." The clay bonds chosen are the products of reputable producers, are in general use in the industry and therefore must be accepted as "true to type." We do not state the trade names of the products as the inclusion of trade names is against the publication policy of the Association.

In the case of the kaolinite type, we selected two plastic fire clay bonds, both of which are widely used for bonding molding sands, bond E from northern Illinois and bond D from southern Ohio. Users in the natural territories served by each of these districts consider them among the best obtainable in their respective districts, the boundaries of which are usually defined by freight rates. In view of the widespread use of plastic fire clay bonds local to other districts than those naturally served by the northern Illinois and southern Ohio bonds tested, it was a matter of regret that physical limitations did not permit the inclusion of other good clays of the same type but from other districts in the tests.

Concerning the relative durability of western versus southern montmorillonite, it is widely recognized in practice that the southern material does "burn out" or lose its strength quickly and could not be used from an economy standpoint strictly on bond cost per ton of castings. But, evaluating the material on the basis as most foundrymen using it have done, first, southern montmorillonite bonded sands have high flowability. From the results of this investigation, southern montmorillonite ranks close to the illite clay in this desirable property. Foundrymen like high flowability in their sands as this means: (1) smoother castings, (2) castings more true to pattern, (3) less swells, (4) less penetration and (5) increased production because highly flowable sands mean (a) less tucking or peening, (b) fewer jolts and (c) less sticking of sands in hoppers.

Secondly, southern montmorillonite possesses lower dry strength than western montmorillonite. Therefore, its use in partial replacement of the high dry strength western material would show improvement in foundry sands results due to: (1) Easier shake-out because of (a) less pounding of flasks, (b) fewer lumps at the shake-out and (c) faster shake-out time; (2) less sand carried out on castings and (3) less possibility of hot cracks or hot tears. Based on the results of this investigation, it is suggested that these advantages can be accomplished at lower cost with the illite clay, as it possesses higher durability.

Mr. Dunbeck has stated we infer that it would be possible for a sand bonded with kaolinite clay to be used for 20 to 40 days without the addition of more bond. In our tests, the kaolinite bonded sand ran 27 heats

without bond additions. We would point out that in making any test comparisons, it is necessary to establish a standard set of conditions, if the test data are to be anywhere near comparable. If it were possible for a foundry to operate on the same basis that these tests were conducted, namely, that the sand would be mulled after each use, that there would be no dilution of the molding sand by core sand, and that thorough reclamation was practiced to secure every possible grain of sand from the castings, it would be possible to secure the results obtained. Naturally, such a procedure in a foundry was impossible, especially in continuous practice.

The results of this investigation may not indicate, as Mr. Dunbeck points out, that it would be unnecessary to bond molding sand heaps with kaolinite clay of the type used in this test for 20 to 40 days, but it does indicate the relative durability of several types of well-known clay bonds used in the industry under the standard conditions as set up in this test procedure. Furthermore, this investigation most certainly shows that foundries can profitably investigate the reduction of bond additions, or the lengthening of intervals between additions, through the use of more durable bonds.

Table 18
GREEN STRENGTHS OF SANDS AS USED IN EACH CAST

<i>Heat</i>	<i>Bond "A"</i>	<i>Bond "B"</i>	<i>Bond "C"</i>	<i>Bond "E"</i>
1	10.2	9.8	10.1	10.1
2	10.0	10.2	9.9	10.0
3	10.1	9.8	10.1	10.0
4	10.0	10.0	10.0	9.9
5	10.0	9.9	10.0	10.1
6	10.0	10.2	10.0	10.0
7	10.0	9.8	10.2	9.9
8	10.1	10.0	10.2	10.1
9	10.1	10.1	10.2	10.2
10	10.1	10.15	10.15	9.9
11	9.9	10.0	10.1	10.1
12	10.1	10.0	10.0	10.1
13	10.15	10.2	10.0	10.0
14	9.9	10.3	10.2	9.8
15	10.0	10.4	9.9	10.2
16	9.9	10.8	10.0	10.3
17	10.1	10.1	10.5	10.7
18	10.3	10.0	10.1	10.7
19	10.1	10.0	10.0	10.6
20	10.15	10.0	10.0	10.9
Average				
20 Heats	10.06	10.08	10.08	10.18

Concerning the points brought out by Mr. Dunbeck on the mulling

test, it is true that foundry mulling times in many cases would not total seven minutes in gray iron or malleable foundries. It is suggested, however, that longer mulling times would be more desirable. The mulling test figures were reported primarily to illustrate that all of the bonds did not develop full strength in the standard mulling time, as covered in the discussion. All of the materials developed upwards of 80 per cent of their 7-minute strength in 4 min., but only 65 to 72 per cent of their maximum potential strength in 4 min. However, with more durable bonds, it is not so important to develop full strength on the first mulling, as most of this undeveloped strength would be obtained in succeeding mullings, as sand is returned in operation of a unit or brought back from heaps to prepare rebond additions or make facing.

Regarding the green strengths of the sands as used in each cast, we are pleased to give these figures in Table 18. They were not reported in the original manuscript because of the importance of more valuable data and our desire to present the data as compactly as possible.

These results show only 1.19 per cent difference in average strengths which should certainly illustrate unusual accuracy. The sand test specification book published by the Association permits 10 per cent variation on identical batches*.

The table which Mr. Dunbeck gives on the mulling tests for the 7-minute standard mulling time has been incorrectly plotted and should be

	2 Min. Dry 5 Min. Wet	2 Min. Dry 8 Min. Wet
Clay "A"—Illite	11.1 lb.)	11.2 lb.
Clay "B"—West. Mont.	9.45 lb.)	9.2 lb.
Clay "C"—South. Mont.	11.7 lb.)	instead of 11.5 lb.
Clay "E"—Kaolinite	10.2 lb.)	10.9 lb.

The correct mulling test strengths, therefore, as compared with the strengths at the beginning of the durability test, with differences are:

	Strength, lb. Durability Test, 7 min. Mulling	Strength, lb. Mulling Test, 7 min. Mulling	Difference, lb.	Percentage Difference
Clay "A"	10.25	11.1	.85	8.3+
Clay "B"	9.8	9.45	.35	3.3—
Clay "C"	10.15	11.7	1.55	15.2+
Clay "E"	10.1	10.2	.1	1.9+

These figures show that in the case of all excepting the southern montmorillonite, the differences are well within the 10 per cent variation which is permitted under A.F.A. test procedure. It should be noted that this 10 per cent variation is allowed on test results for the same batch of sand. We were able, however, throughout the test, to maintain much greater accuracy than specified. The explanation for the greater variation on the southern material, in the mulling test, would be in the

* TESTING AND GRADING FOUNDRY SANDS AND CLAYS, Paragraph 174, Page 43.

difference in the mechanics of the two tests. As was outlined, the mulling tests were taken on an all new batch of sand by removing samples for test at the time intervals shown, whereas the initial batch for the durability test was prepared by a constant mulling time of 7 minutes.

To infer that the values of the entire results are questionable because of the above variations is almost absurd, when it is considered that the two tests are not identical procedures. To further prove the care and accuracy exercised in the entire test routine, we present the following comparative green strength figures on the three different operations proving that the percentages of clay used were correct:

	<i>Green Compression Strength, lb.</i>		
	<i>Experimental Batch</i>	<i>Batch No. 1 Pilot Test</i>	<i>Batch No. 1 Final Test</i>
Bond "A"	10.3	10.06	10.25
Bond "B"	9.5	10.1	9.8
Bond "C"	9.8	10.0	10.15
Bond "E"	9.8	10.1	10.1

We believe that these figures should clarify any question of reproducibility.

Regarding kaolinite versus southern montmorillonite, we have no actual data on comparative amounts required in foundry practice. However, in many ferrous foundries with which we are familiar, it has been impossible to use the southern material for sufficient length of time to obtain definite comparisons, as poor durability has necessitated either discontinuing its use or reverting to a blend with other clays.

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